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ICE ATLAS

EASTERN CANADIAN SEABOARD

By

W. E. MARKHAM

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ABSTRACT

This publication presents an analysis of ice conditions in the Gulf of St. Lawrence and in the waters of Newfoundland and Southern Labrador. Data are presented about the location, abundance and nature of the ice and its variation during the winter and spring months.

Related data concerning the meteorology and oceanography of the area are included so that the atlas can be used as a major reference source in planning studies and during actual operations on board ship.

FOREWORD

The Atmospheric Environment Service has been conducting ice reconnaissance since 1958 in the Gulf of St. Lawrence-Newfoundland area in a program which was an enlargement of an earlier spring ice patrol conducted by the Department of Transport. A need for the analysis of the collected data became apparent in the early 1960's and this Atlas is the culmination of that work. The inter-relationship between ice conditions and several atmospheric parameters has been constantly monitored on a day to day, week to week, and season to season basis. As a result, although the ice records are relatively short from a statistical viewpoint, the longer meteorological records substantiate to a great extent the averages that have been produced.

The number of ice observers, ice forecasters, summer students, ice technicians, draftsmen and typists who have assisted in the work is far too long to acknowledge their input individually, but Mrs. J. Blackburn and Mrs. D. Spencer who designed and conducted most of the computer work and Mr. F. Geddes who prepared the manuscript ice charts and graphs do merit special mention. Without their efforts this atlas would still be merely a desirable project for the future.

CONTENTS

		Page
Abstract		iii
Foreword		iv
Geographical Reference Chart		viii
Introduction		1
Chapter 1	Annual Ice Regime	7
	Fortnightly Ice Charts Gulf of St. Lawrence, Newfoundland and Labrador Waters	17
Chapter 2	Icebergs	43
Chapter 3	Oceanography	53
Chapter 4	Meteorology	57
	Analysis of winter winds in central Gulf of St. Lawrence	60
	Meteorological Tables and Graphs	63
Bibliography		81
Appendix A	Ice Terminology	83
Appendix B	Ice Symbols	95

TABLES AND GRAPHS

Table		Page
1.	Freezing Degree-Day Data	8
2.	Number of Days with Measurable Rain and Snow	57
3.	Number of Days with Fog	58
4.	Mean Hours of Reduced Visibility	59
Extreme and Mean Temperature Graphs		63-66
	Quebec, Mont Joli, Sept Iles, Fox River, Campbellton, Charlottetown, Sydney, St. Andrews, Stephenville, Harrington Harbour, St. John's, Bonavista, Twillingate, Battle Harbour, Cartwright, Goose Bay.	
Wind Roses – Directional breakdown of the duration of all winds and of winds >29 km/h, December to May inclusive		67-72
	Quebec, Sept Iles, Chatham, Grindstone Island, St. John's, Goose Bay.	
Wind Roses – Directional breakdown of the duration of all winds, December to May inclusive		73-79
	Mont Joli, Fox River, Campbellton, Charlottetown, Sydney, St. Andrews, Stephenville, Bonavista, Twillingate, St. Anthony, Battle Harbour, Cartwright.	

ILLUSTRATIONS

Figure		Page
1.	NOAA – 4 VHRR visual imagery showing extensive ice pack off Labrador and northern Newfoundland	2
2.	NOAA – 4 VHRR visual imagery 08 March 1976 Orbit # 5996	3
3.	LANDSAT imagery 10 February 1976. Channel 6, Track 9, Frames 25 & 26	4
4.	Iceberg Census in Baffin Bay 10-18 August, 1949	44
5.	March – Monthly iceberg limits	48
6.	April – Monthly iceberg limits	49
7.	May – Monthly iceberg limits	50
8.	June – Monthly iceberg limits	51
9.	Generalized Mean Currents	56
10.	Grease Ice	88
11.	Nilas and Grey Ice	88
12.	Grey and White Ice	88
13.	Grey-White Ice	89
14.	Strips and Patches of Ice	89
15.	Ice Patch with Defined Edge	89
16.	First Year Ice with Puddles	90
17.	Rafted Ice	90
18.	Ridges and Hummocks	90
19.	Open Water	91
20.	Very Open Pack Ice	91
21.	Open Pack Ice	91
22.	Close Pack Ice	92
23.	Very Close Pack Ice	92
24.	Compact or Consolidated Pack Ice	92
25.	Iceberg	93
26.	Bergy Bit	93
27.	Growler	93

QUEBEC
NEW BRUNSWICK
P.E.I.
NOVA SCOTIA
NEWFOUNDLAND
GASPÉ PENINSULA
ANTICOSTI ISLAND
GULF OF ST. LAWRENCE
CAPE BRETON ISLAND
CABOT STRAIT
BAY OF FUNDY
St. Lawrence Estuary
Cape Whittle
Flowers Cove
St. Anthony
Battle Harbour
Cape Bauld
Bonne Bay
Corner Brook
Stephenville
Port au Port Pen.
Cape St. George
Bay of Islands
Cape Anguille
St. Andrews
Cape Ray
Grindstone Is.
Magdalen Is.
Cape North
Sydney
Canso
Halifax
Yarmouth
Digby
Annapolis Royal
Charlottetown
Summerside
Cape Tormentine
Chatham
Bathurst
Campbellton
Dalhousie
Matane
Mont Joli
Rivière du Loup
Cap de la Madeleine
Gaspé
Port Daniel
Percé
Sept Iles
Point-des-Monts
Baie Comeau
Havre Saint-Pierre
Natashquan
Blanc Sablon
Labrador City
Wabush
Goose
Terrington Basin
Lake Melville
Hamilton Inlet
Battle Isle
Strait of Belle Isle
Notre Dame Bay
Twillingate
Fogo Island
Cape Freels
Bonavista
Gander
Botwood
Comfort Cove
Baccalieu Is.
St. John's
Avalon Peninsula
Cape Race
Placentia Bay
Miquelon (Fr.)
St. Pierre (Fr.)
Sable I.
Scatarie I.
Jacques Cartier Passage
Cabot Strait
Anticosti Island
Heath Point
Cape Ray
Cape Anguille
Cape North
Cape Breton Island
Prince Edward Island
New Brunswick
Nova Scotia
Newfoundland
Quebec
70°
65°
60°
55°
50°
45°

INTRODUCTION

The Eastern Canadian Seaboard is a term which has been selected to designate the coastal waters of the Atlantic Provinces and Quebec from the American border as far north as latitude 55N. Thus, it includes the Gulf of St. Lawrence, the St. Lawrence Estuary and River as far as Quebec city, the waters of Newfoundland and the coast of Labrador from Strait of Belle Isle to Hamilton Inlet. Within this broad zone, essentially ice free conditions are found in the Bay of Fundy and along the mainland coast of Nova Scotia; seasonal ice of local origin is found in the Gulf of St. Lawrence and Cabot Strait. Eastern and northern Newfoundland and the Labrador coastal waters are affected by local ice in the early part of the winter but "imported" floes from northern waters form an increasing proportion of the pack during late winter and spring. Old ice floes from Arctic areas are known to intrude on some occasions.

The areas being covered are those in mid latitudes, on the eastern edge of the North American land mass. In winter, cold air from the northern plains can be carried seaward, resulting in temperatures far below the freezing point, causing superstructure icing and rapidly increasing the volume and extent of the sea ice present. On the other hand, migratory low pressure centres from the Mississippi Valley or the southeastern United States may result in warm air from low latitudes sweeping northward and creating melting conditions that last anywhere from a few hours to several weeks. The winter seasons vary considerably in severity depending upon the relative frequency and the paths of these migratory storm centres.

Mean temperatures for those months when ice usually occurs - December to May inclusive - vary across the area from 2 to 3°C at Sable Island and Dartmouth, Nova Scotia, to 0 to -1°C in Cabot Strait and the northern Grand Banks, -2 to -4°C in the Central Gulf of St. Lawrence and northern Newfoundland and -6 to -8°C along the north shore of the Gulf and in the Hamilton Inlet area.

These latitudes represent the southernmost extension of sea ice in North American waters and, since mean temperatures during the cold season are not far below the freezing point, there are great variations from year to year in the extent of the ice. Its actual location is affected by prevailing winds but the volume of ice formed is directly related to winter air temperatures. 1957-1958 was the mildest winter in the past one hundred years at Halifax and the mildest in the central Gulf of St. Lawrence since the weather station on Grindstone Island was opened in 1933. The ice in the Gulf during 1957-58 was confined to the coastal waters from Gaspe Peninsula to Prince Edward Island to Cape Breton Island, while in east Newfoundland the pack was limited to a narrow belt from Hamilton Inlet to Notre Dame Bay. No ice entered Cabot Strait, nor was any carried southward beyond Fogo Island. In 1971-72 on the other hand, the ice formed early, was very extensive during the winter and spring, and was late melting in both the Gulf and Newfoundland areas. The winter ranked in the coldest five of the past forty years.

The Department of Transport Marine Services began an "Ice Patrol" in the Gulf of St. Lawrence in 1940 with the apparent intent to determine the date that open water navigation into the St. Lawrence River ports became feasible. This patrol operated during the spring months until the late 1950's and was then supplanted by a Meteorological Branch ice reconnaissance and forecasting program. This service operates throughout the winter and also supports shipping in all ice-encumbered Canadian waters. Service is provided on the Eastern Seaboard until the ice clears and then covers the Hudson Bay Route and Arctic waters from July until freeze-up.

Significant winter shipping into the Gulf of St. Lawrence began in the early 1960's and ship movements rose steadily from about 250 between December 15 and March 31 in 1963 to over 1,000 in the early 1970's. During this period, Department of Transport has operated an Ice Information Office in Sydney, or later Dartmouth, to direct the commercial vessels and provide support with icebreakers when necessary.

The Canadian ice reconnaissance and forecasting program is now operated by the Atmospheric Environment Service (AES) of Environment Canada but this is a change in name rather than a change in personnel or methods. In the early years, aircraft were chartered for each specific area of operations and the hours of flying were in the range of 600 per year. Long-term year-round charters were instituted in the mid 1960's and hours of flying rose to about 2,400 per year. Since then the total has gradually risen and is now over 4,000 when helicopter and National Defence flights are included. AES ice observers have always been assigned to the DOT icebreakers to report the ice they encounter, to provide localized helicopter reconnaissance and to brief the captain and officers about weather and ice conditions on a day-to-day basis.

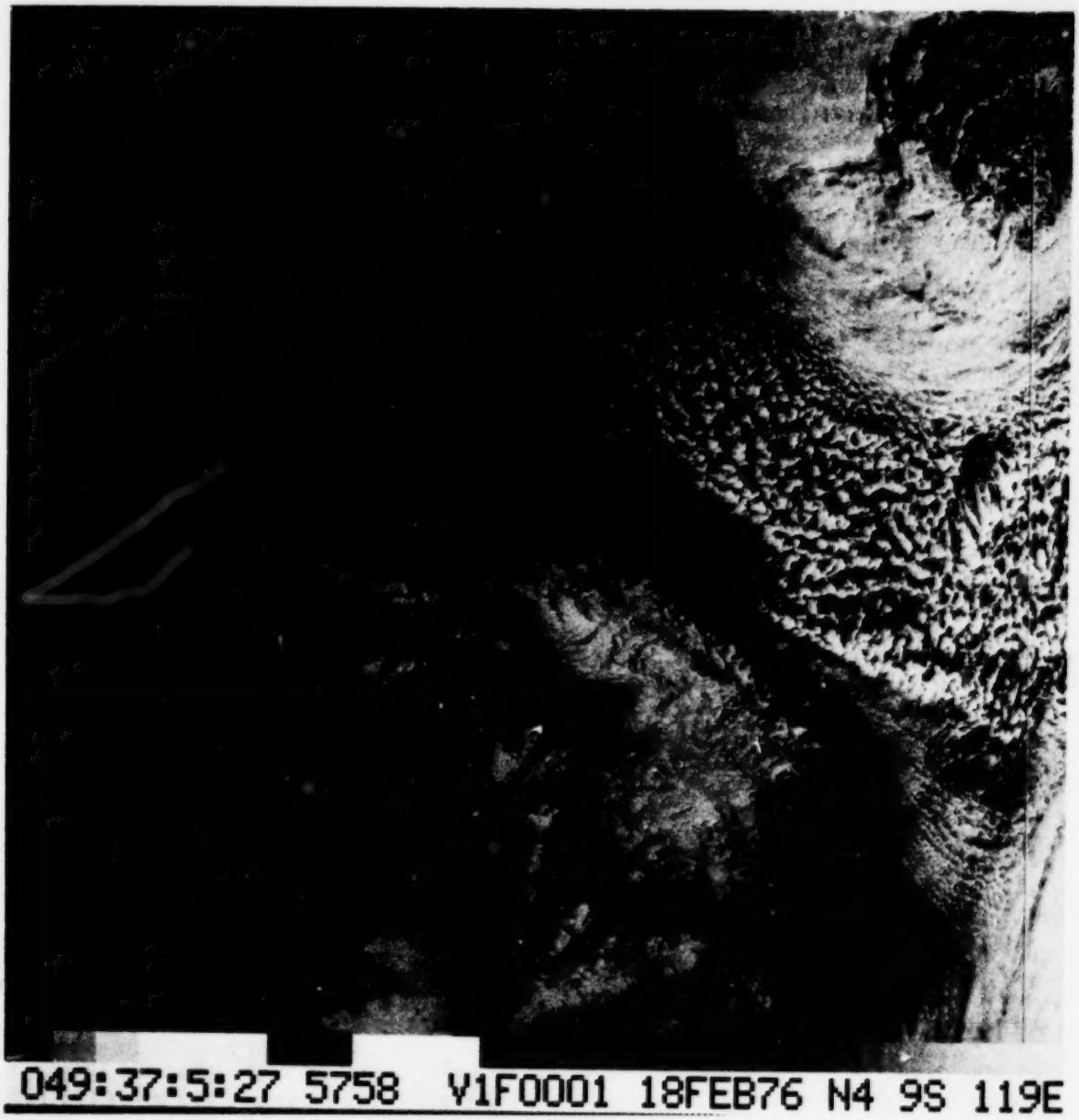


Figure 1 – NOAA - 4 VHRR visual imagery showing extensive ice pack off Labrador and northern Newfoundland. Resolution is 1 km. Notice the darker area where the ice is either thinner or partly dispersed or both between Strait of Belle Isle and Spotted Island, the apparently open lead which could contain new ice from White Bay to Cape Bauld and the very loose nature of the eastern edge of the pack. The wind flow is shown by the arrangement of the cumulus clouds in "streets" beyond the pack ice.

The white lines represent the 45° viewing angle from the satellite and are about 800 nautical miles apart. The distortion caused by the earth's curvature is partially evident. This imagery was created in Washington from the Wallops Island receiving station.

Figure 2 – NOAA - 4 VHRR visual imagery 08 March 1976 Orbit # 5996.

An enlarged section of the satellite imagery after processing by computer to remove the distortion caused by earth curvature. Broad open water areas are evident along the North Shore and on the New Brunswick coast but very congested conditions prevail on the west coast of Newfoundland. A west-north-west wind is indicated by the clouds streaming away from Southwest Point - Anticosti.

Figure 3 – LANDSAT imagery 10 February 1976. Channel 6, Track 9, Frames 25 & 26.

The ice to the north of Anticosti Island is dark-toned (and thin) close to the North Shore but whiter and formed into more definite floes near the Island. To the south, there is an open flaw lead outside the fast ice along most of the coast. The off-shore floes are smaller than in Jacques Cartier Passage until the area east of Gaspe is reached. The large white spot on the Island is the site of a large forest fire many years ago. Clouds and cloud shadows are present in the upper left corner of the two pictures.

The aerial ice observations flowing into Ice Forecasting Central, combined with daily meteorological data, permit the preparation of comprehensive summary charts to document the variations in ice conditions during the season. After some thought, a weekly interval between charts was decided upon and regular preparation began in 1959. There is now over fifteen years of data available for analysis, permitting the development of a reasonable ice atlas for the area. Extremes and medians that have occurred during the interval are presented, and the parallel meteorological data that is available have been used to make this relatively short record more meaningful.

Ice atlases have their greatest use in the planning stages whether it be for a single voyage, a regular service to one or more ports, a special vessel for year-round use in the area, or for special short-period projects in the offshore area. With this in mind, an attempt has been made to include in the atlas, an indication of the location of the ice throughout the season, its abundance, its thickness, and also additional data on the factors that control these parameters. Lastly some data on actual average and extreme conditions are also illustrated.

As mentioned above, summary charts of ice conditions based on aerial and shipboard observations, shore reports from lighthouses and other coastal installations, combined with prevailing wind and temperature conditions have been produced in Ice Forecasting Central since 1959. Soon after the program began, output from meteorological satellites became available and these have had an increasing usefulness in broadening the area of the charts and the details they contain. At first, the TIROS series viewed the earth with a resolution of about 10 km but the "look angle" was usually oblique. Later, the Automatic Picture Transmission and the vertical viewing of the ESSA satellites made a vast improvement in the usefulness of the imagery and a reasonably accurate plotting of ice edges and leads became possible. More recently the NOAA series with visual and infra-red Very High Resolution Radiometers (VHRR) having a resolution of 1 kilometre (Figures 1 and 2) have increased the data available from space by at least an order of magnitude.

Imagery from the LANDSAT satellite (figure 3), has also been used since 1973 but although this platform has sensors offering 100 metre resolution, the coverage is cyclical (2 days in 18), and cloudiness is a very significant drawback along the Eastern Seaboard during the winter. Acquisition of data east of Sydney and Cartwright is also rather difficult so the input of satellite data for ice charts of that area has been very limited.

Many of the weekly ice charts appear in the annual report, Ice Summary and Analysis – Eastern Canadian Seaboard which has been published for the decade 1964-1973. The ice data on the weekly charts was digitized on an element by element basis and the computerized output for the period 1963-1973 has recently become available. To this, the extremes from the years 1959-1962 and 1973-1974 have been manually added so that although the medians represent eleven years of data, the extremes cover a full sixteen years.

The data was digitized using a one degree longitude by one half degree latitude grid so that each report represents an area of about forty by thirty nautical miles, except in coastal regions. Some slight refinement of these limits may have been possible but here the problem of the accuracy of the data and the increased volume that would result must be balanced against the gain that more precision would produce. After due consideration the 40 x 30 nautical mile sample was considered the best and was adhered to throughout the analysis.

When the AES ice reconnaissance program began, there was no international agreement on terminology or symbology for ice charts. The matter of terminology was soon resolved when the World Meteorological Organization adopted a basic group of terms which has since evolved into a comprehensive list. This terminology, along with several illustrations, is given in Appendix A on page 83, and is used through this publication.

There is, as yet, no internationally accepted system of symbols for ice charts and that used in this publication is a unique Canadian method which shows the amount of ice and its age classification by means of a single digital report. Details of this system are given in Appendix B on page 94.

Chapter 1

ANNUAL ICE REGIME

The shorter days of autumn result in decreasing air temperatures and, in the Gulf of St. Lawrence – Newfoundland area, freezing conditions first develop along the north shore of the Gulf in the second week of November. There is, of course, a large heat reserve in the sea and this retards the southward spread of colder conditions, for it is not until the end of the month that the daily mean temperatures fall below 0°C in Prince Edward Island and the Magdalen Islands, and the second week of December in Cape Breton Island and the Avalon Peninsula.

Freezing degree-day (FDD) accumulations are very useful in comparative studies of ice regimes from area to area and from year to year. A freezing degree-day is defined as the departure of the daily mean air temperature by one degree below the freezing point. Accumulations are built up day-by-day throughout the winter season. Thus, on a day when the maximum temperature is -8°C and the minimum is -14°C, the daily mean of -11°C means that there were 11 degrees of frost on that day. If these identical conditions persisted for four days (which is highly unlikely in nature) there would be an accumulation of 44 freezing degree-days. Melting degree-days (departures above the freezing point) can also be utilized in the study of ice decay. A list of comparative figures for the Gulf of St. Lawrence – Newfoundland area is shown in Table 1, as well as some of the recorded variations. 1957-1958 was the mildest winter at Grindstone Island since the weather station was opened in 1933 – 230 freezing degree-days. From longer records in the general area it is evident that this was also the mildest in about 100 years. The coldest years listed, 1958-1959, 1960-1961 and 1971-1972 had about 925 FDD, well above the average of 650 but these include only the past 25 years. Earlier records indicate that the winters of 1922-23, 1933-34 and 1934-35 were significantly colder still for the FDD accumulations reached 1120 to 1220 in each of these seasons. This is as much colder than the 1972 winter as it was itself below normal. We have no record of the ice conditions which prevailed but stories of an "ice bridge" between Cape Breton Island and Newfoundland may relate to these winters.

In considering the ice regime of an area such as the Gulf of St. Lawrence or the waters surrounding Newfoundland, there are two major climatic factors that stand out as controls. First, the mean temperatures during the winter do not fall very far below the freezing point and as a result cold and mild winters have a very significant effect on the extent and severity of the ice cover. At Grindstone Island, in the Magdalens, the mean daily temperature is below 0°C for about 130 days and the total accumulation of freezing degree-days averages 650. The mean is thus only five degrees below freezing. Normal variations in weather – mild and cold spells – have a high percentage effect on this total. A month that is 3 degrees above normal, a quite ordinary occurrence, will reduce the accumulation by about 100 FDD – 15% of the winter total. As one moves northward, the total amount of winter frost increases and the significance of variations of this type decreases progressively.

The second climatic factor is that winter winds from the west and north will nearly always be cold and dry whereas those from the sector from west through south to northeast will be mild and moist. This has a decided effect on the location of areas of ice dispersal and congestion once it has formed.

A. GULF OF ST. LAWRENCE

N.B. *A series of ice charts depicting median ice concentrations and maximum, minimum, and median extent of the ice follows this chapter.*

(a) Normal Patterns of Development

The first ice formation in this area occurs in the St. Lawrence River itself and floes are carried down-stream to the Quebec area in the first week of December. This ice is thin and it is primarily a fresh-water type but it spreads downstream gradually, aided by wind flow and ebb tides. By mid-December it reaches the mouth of the Saguenay River but, at the same time, ice formation in the salt water of the estuary also produces a significant area of ice cover – new and grey ice types. By 25 December this ice

Table 1

FREEZING DEGREE DAY DATA

1953 - 1975

	Normal Freezing Degree Day Accumulations							RECORDED VARIATIONS				
	Date Freezing Begins	Dec. 18	Jan. 1	Jan. 29	Feb. 26	Mar. 26	Total in Normal Winter	Recorded Maximum	Year	Recorded Minimum	Year	Date Melting Begins
Quebec	Nov. 19	180	330	615	980	1155	1175	1470	1959	790	1958	Mar. 29
Mont Joli	Nov. 16	170	305	620	925	1090	1145	1480	1972	735	1958	Apr. 7
Sept Iles	Nov. 9	175	440	815	1180	1390	1480	2010	1972	855	1958	Apr. 11
Fox River	Nov. 19	125	230	485	760	920	975	1330	1972	460	1958	Apr. 12
Charlo*	Nov. 19	165	305	620	925	1135	1155	1600	1972	610	1958	Apr. 5
Summerside	Nov. 29	65	145	350	560	665	695	950	1972	300	1958	Apr. 4
Sydney	Dec. 2	35	75	205	375	485	515	845	1961	95	1958	Apr. 4
Grindstone Is.	Dec. 1	45	105	265	470	600	650	925	1972	230	1958	Apr. 14
Stephenville	Dec. 5	50	95	230	405	525	570	895	1972	55	1958	Apr. 7
Harrington Hbr.†	Nov. 16	155	285	560	850	1030	1145	1710	1972	530	1958	Apr. 19
St. John's	Dec. 11	35	70	180	305	380	425	700	1959	110	1958	Apr. 6
Comfort Cove ‡	Dec. 5	45	100	240	410	525	600	1000	1972	175	1958	Apr. 10
St. Anthony	Nov. 17	125	225	465	720	905	1035	1590	1972	520	1958	Apr. 21
Battle Harbour	Nov. 13	160	275	540	825	1010	1140	1730	1972	670	1958	Apr. 22
Goose Bay	Oct. 31	335	540	975	1395	1665	1830	2515	1972	1005	1958	Apr. 22

*Includes Campbellton prior to 1967
† Includes Cape Whittle 1963-1968
‡ Includes Twilligate prior to 1967

Source c data – daily teletype reports of maximum and minimum temperatures

usually spreads as far seaward as Baie Comeau and Cape Chat and even at this early stage the ice is thicker and more plentiful along the Gaspe coast than it is along the north shore of the river. This difference is apparent in mean and median conditions and, on specific days, open leads occur along the north shore when there are west, northwest or north winds. The ice is more uniformly dispersed with east and northeast winds.

As well as ice formation in the St. Lawrence River, the middle of December also sees coastal ice forming along the shallows of the New Brunswick coast from Bathurst to Cape Tormentine and eastward as far as Pictou, N.S. This ice, too, is thin and is well dispersed for the westerly winds that accompany colder weather tend to spread the floes into the main body of the Gulf or across Northumberland Strait.

At the beginning of January the ice cover spreads down the estuary as far as Pointe des Monts and Cap de la Madeleine and, although the total ice cover loses its mean variability from one side of the river to the other, the general drift tendency and the normal wind directions produce thicker ice on the Gaspe coast as they did in the initial formation stages. In the southwestern Gulf, the ice cover increases in concentration rather than in area for the ice is still very thin and is subject to melting if it is carried offshore to areas where convectional cooling of the sea water has not proceeded as far as the freezing point. During January the ice spreads gradually seaward and grows in thickness until floes of grey-white ice begin to develop.

From the manner in which the ice spreads over the Gulf it is quite apparent that a very high proportion of the ice found in the area is formed within the Gulf itself (principally in the western and northwestern sectors), and most of the remainder is formed in the estuary. Tales of ice from the Labrador coast filling the Gulf of St. Lawrence are nothing but myths, as is the concept that a dam across the Strait of Belle Isle would result in an ice free Gulf of St. Lawrence. Although the ice is very mobile and much of it flows into the Atlantic Ocean through the Cabot Strait, replacement by freezing in the persistent open leads along the North Shore is continually taking place throughout the winter.

In February the ice continues to thicken and begins to drift through Cabot Strait but a lead usually remains along the west coast of Newfoundland beyond Bonne Bay until mid month. From the latter part of February until the middle of March, the ice in the Gulf is near its maximum thickness and extent. The lead along the Newfoundland coast is closed and there is plentiful ice in the southern approaches to Cabot Strait.

In the estuary the tendency for west to east motion of the ice is very apparent for leads are common along the shore from Pointe des Monts to the Saguenay River, and congestion is prevalent along the Gaspe coast. Winds, water motion and the Coriolis force all contribute to this motion pattern producing thicker congested ice that follows the shore as it moves into the main body of the Gulf. A very difficult ice area is created at the mouth of the Bay of Chaleur. The ice continues south and southeastward and combines with ice from the area west of Anticosti and those floes developed within the Gulf to fill the whole area from Gaspe Peninsula to Cape Breton Island with large floes of relatively thick ice. Leads and areas of dispersed ice are created along the New Brunswick and Prince Edward Island shores in response to the wind but, in general, the southwestern section of the Gulf becomes congested with thick ice in very large floes that can exert considerable pressure against Cape Breton Island and the northwestern shores of the Magdalen Islands.

Through the centre of the Gulf, the ice concentrations tend to be somewhat lower, a proportion of young ice formed in the Pointe des Monts – Sept Iles area is present and leads may also form in the lee of Anticosti Island. There is a tendency for ice to drift directly from Gaspe Passage to Cabot Strait but this is very much subject to variations in wind conditions. Because of their greater mobility and the mixture of ages, the floes are much smaller than in the southwestern Gulf but the first year ice that is present is still in the 60-90 cm range of thickness at the middle of March and poses a hindrance to navigation.

In the northeastern Gulf the ice motion is much more restricted for the wind-induced drift from west to east is partly opposed by water motion northward along the Newfoundland coast. The result is frequent congestion in the Bay of Islands area, little efflux of ice into Cabot Strait, and generally an area of thick, deformed ice from Port au Port Peninsula northward. Coastal leads can develop in this area when easterly winds prevail but lateral motion of the ice along the coast does not often develop.

(b) **Patterns of Dispersal and Melting**

Dispersal of the ice begins in early March and is first evident in the estuary near the mouth of the Saguenay River where ice concentrations fall to the 3-5 tenths range. Tidal upwelling of warmer water at the western limit of the deep channel through the Gulf and estuary combined with the general

spring rise of air temperatures is responsible. This upwelling is a feature of the location and a certain amount of open water is nearly always present in this area. Although ice formation is rapid in mid-winter and ice concentrations are high, much of the ice is thin. In mid-March when mean air temperatures average -4°C and afternoon temperatures are usually above freezing, ice formation is very slow and open water results from the upwelling and reduced ice formation. The absence of ice cover also permits an increase in solar warming of the water for, although snow and ice reflect a large proportion of the insolation falling on them, water absorbs most of this energy input. Openings in the ice cover are thus extremely important in the spring of the year for they act as centres of ice decay.

By late March the clearing from the Saguenay River area spreads down to Anticosti Island and along the north shore to Cape Whittle. Decreasing median ice concentrations are evident through the center of the Gulf but congestion persists in the southwestern portion and in western Cabot Strait. Break-up of the ice in the St. Lawrence River and the upper estuary at the same time, results in some intrusions of ice past the mouth of the Saguenay but this ice is well dispersed and is rarely a navigational problem.

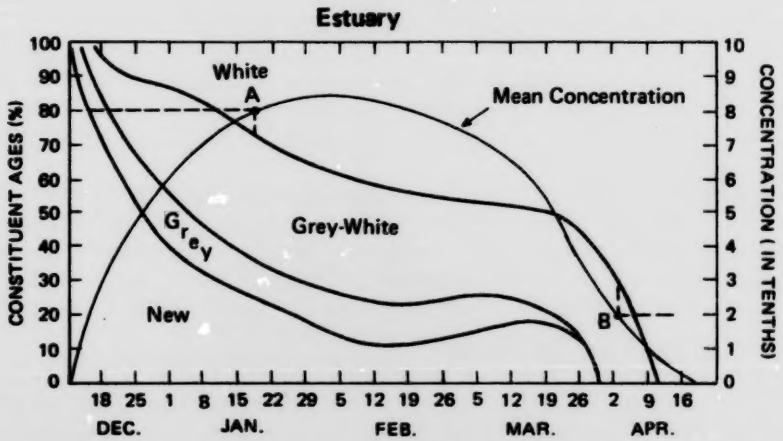
In early April the estuary is usually free of ice, the inner ice edge has passed Anticosti Island and ice concentrations are beginning to decrease in the area between Cape Ray and Heath Point (Anticosti Is.). By the following week an open water route through the Gulf is often present between one large area of ice in the southwestern Gulf and the waters surrounding Cape Breton Island and a second area from Port au Port Peninsula to the Strait of Belle Isle. Once this separation has occurred, navigation into the estuary is unhindered and re-formation of an ice barrier across the shipping route does not occur. By mid April the northern ice has retreated beyond Cape Whittle, and Northumberland Strait has usually cleared. Complete melting in the southern Gulf is usually accomplished by mid-May and persistence of ice into June has not occurred in the past 13 years and only once since 1940. The Strait of Belle Isle is somewhat slower to clear for sea ice usually persists until the end of May and may remain in the eastern approaches until early July.

(c) Age Classes of Ice Present and their Navigability

The fore-going discussion has concentrated on the amounts, locations and movement of the ice without much attention being paid to its thickness or navigability. In order to complete the picture, a percentage break-down of the various age classes has been done which, in many cases, can indicate just how the ice will affect navigation by a particular vessel.

Because the number of years of data is limited, it was felt that an age break-down for specific locations would not be truly representative and that a generalized picture would be preferable. Three locations in each general area were therefore analyzed and the resulting curves were then plotted and slightly smoothed. To this graph the mean concentrations have been added for the same locations.

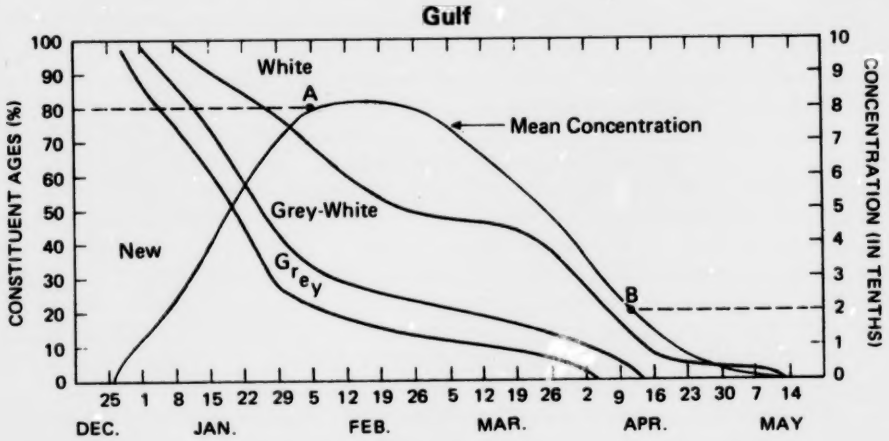
In the estuary the appearance of all classes of ice occurs in as little as a week because most of the floes that appear are actually carried down river into the area. The rate of growth to the grey-white stage is rapid but, because of tidal effects above the Saguenay and the combined effect of wind and the Gaspe Current in the eastern portions, the proportion of white ice remains low until melting removes the thinner categories of ice.



In this graph the percentage of new ice covers the lowest and white ice the uppermost areas with grey and grey-white ice in the centre portions. For example on January 22nd there is usually about 25% new ice, 10% grey ice (making 35% of the pack 15 cm or less in thickness), another 35% of the floes are in the grey-white category and the final 30% is white ice (greater than 30 cm). At this time the mean concentration is about eight tenths.

One additional function can be performed by a graph of this type. Suppose a particular vessel is capable of operating through eight tenths of ice providing no more than two tenths of it (25%) is in the white ice category. In planning the shipping activity for that vessel, transits of the area would cease on date A – Jan. 19, and recommence on date B – April 3. Variations from one season to another will be significant but cannot be included at this planning stage.

The fact that this is a generalized graph for the whole estuary should also be taken into account. Access to a port such as Baie Comeau would be easier than indicated for there is appreciably more new and grey ice on the north shore than on the Gaspe coast and for that area the graph gives a pessimistic picture. For Quebec it should be reasonable but for places like Riviere du Loup or Matane it will provide a better than average summation.



As for the estuary, this graph presents a generalized picture of both the age break-down of the ice in the Gulf and the variation of concentration with time. Four locations were averaged in preparing it. Compared to the estuary, the build-up in ice thickness and of concentration is appreciably slower and the clearing covers a more protracted period. However, the proportion of white ice rises to a higher range after late February than it does in the estuary and this to a degree explains the slower clearing rate. Navigability of the ice for vessels with specified capabilities can be estimated as noted above. For the same restrictions the dates in this area are February 5 and April 12.

Another aspect affecting the navigability of ice is its topography which is a record of past pressures exerted on it and can also be an indication of existing pressure. Although collection of laser profilometer traces of ice topography in the Gulf of St. Lawrence has begun, no detailed analysis of the records has been possible as yet, so statistical data cannot be presented. However, we do know that most ridges are in the 0.5 to 1.5 m height range and their frequency is between 2 and 6 per nautical mile. Extreme ridges in the 3 to 4 m range do occur in coastal areas such as west Newfoundland and northern Cape Breton Island but the ice is generally very mobile and repeated build-ups are not common.

From soundings and studies in other areas it has been found that in this type of ice, keel depths are 4.5 to 5 times the ridge height but the mass below the sea surface is only lightly frozen together and the keel itself contains about 30% void space (water). Average slope of the ridge side is 25° and of the keel 35° so one can easily compute that the width of the ridge is over four times its height and the width of the supporting keel is nearly 13 times the height of the ridge above it.

The development of pressure situations obviously relates to wind conditions and an onshore flow can easily be anticipated in any particular area. More difficult to recognize or forecast are those situations where a close pack ice cover is moving into a funnel-shaped area such as Gaspe Passage or parts of Northumberland Strait. In these cases the rate of influx may create pressure as the breadth of the channel decreases.

There is no significant data on the distance that pressure can extend from shore but this must be related to original ice concentrations and to the duration and strength of the onshore component of the wind. Ice thickness may also be a factor as well as ice temperature (stage of deterioration or of growth).

(d) **Features of the Area**

(i) When ice drifts through Cabot Strait into the Atlantic Ocean, water currents encourage its southward drift past Sydney and down to the area of Scatari Island. The entire area of the strait only becomes covered with ice when wind drift holds it against the Newfoundland shore. As soon as the winds diminish or change direction, inflowing currents around Cape Ray will soon create a lead northward towards Cape Anguille and eventually to Cape St. George.

A pattern is usually established each winter for the general direction of drift of the ice once it leaves the Scatari Island area. In some years, usually the colder ones, the pack continues eastward and has been known to reach as far as St. Pierre and Miquelon. In other years, when easterly winds are common it follows the Cape Breton coast, may fill Chedabucto Bay and continue southwestward as far as Halifax. Weak water currents strengthened by the wind flow, are responsible for the extent of this motion. Most often the drift is generally southward but the distance it moves is not great.

(ii) Swell from storms in the Atlantic Ocean can enter through Cabot Strait and cause extreme fracturing of the floes in the Magdalen Island – Cabot Strait areas, its persistence and penetration into ice covered waters is much greater than even large seas can accomplish.

(iii) Because the ice is mobile, the floes are small, ridging is rather extensive and puddling of the ice in this area is rarely well developed. The ice is more subject to melting from below as a result of warmer water than it is to melting because of heat absorption in surface puddles.

(iv) Very large floes, locally called "battures", are sometimes encountered in the northwestern Gulf of St. Lawrence in March. These are dislodged fragments of the fast ice which forms over shoals along the south shore of the estuary which have been subsequently dislodged "en masse" by spring tides during a mild spell. Battures are noted for their size, roughness, and dirtiness, and may carry a very thick snow cover which makes them very difficult to penetrate. They constitute a hindrance to navigation by engulfing ships which encounter them rather than being a hazard causing structural damage.

(v) Fast ice is not a feature of the Gulf for in most coastal areas it is of limited extent. It does form in Caraquet and Nepissiguit Bays however, and in all the smaller bays and inlets from Gaspe to Cape North, from Pointe des Monts to Blanc Sablon and from Cape Anguille to Flowers Cove. Melting "in situ" is the normal decay procedure in these smaller areas.

B. NEWFOUNDLAND AND LABRADOR WATERS

N.B. *A series of ice charts depicting median ice concentrations and maximum, minimum, and median extent of the ice follow this chapter.*

(a) **Normal Patterns of Development**

Because of their latitude, location away from the ocean, and low salinity Terrington Basin and Lake Melville are the first areas along the seaboard to freeze and both are consistently ice-covered by mid December. The initial freeze-over at Goose Bay actually occurs in mid November but growth is slow and ice thickness until mid December is nearly always less than 30 cm. Formation spreads more slowly across Lake Melville, for there the ice is affected by wind conditions and it is not until 11 December that a complete cover is consistently present. Ice appears in the coastal waters in the following week and the median ice edge spreads southward to Battle Harbour by Christmas week and into the Strait of Belle Isle by the beginning of January.

Variations in the extent of ice at this time of year are great because both winds and temperatures are effective in changing the location of the edge. A winter such as 1971-1972 during which temperatures were consistently below normal in Labrador, with northwesterly winds in December, resulted in very extensive development of the ice cover and made a significant difference in the "extreme southern limit of ice". Although the Strait of Belle Isle is normally easily navigated until the first week in January, this was far from the case in 1972 when navigation became impeded by 14 December.

During January, the mean ice edge spreads southward reaching White Bay and western Notre Dame Bay near the end of the month. At this time the Freezing Degree Day accumulations at St. Anthony are easily great enough to cause extensive ice cover but this is not true at Twillingate or St.

John's. The implication here is that all the ice in the area from Botwood to Hamilton Inlet at this time is locally formed and consequently is thin and relatively easy to penetrate.

During February the ice belt broadens considerably in width, the southern limit progresses to Cape Freels by mid month and to Baccalieu Island by the beginning of March. At this stage the measured ice thicknesses at Goose Bay and Cartwright are in the 60-75 cm range and those in the pack north of Fogo will be in the 50-60 cm region for the floes there will have endured only slightly milder temperatures. Water currents in this area result in a southward ice drift of about three degrees of latitude per month making the floes significantly thicker than one would expect from local conditions. Later in the spring Arctic ice can appear in this area as will be explained later.

The maximum southern extent of the ice occurs in March when it reaches 47° 30′N but in this month the ice belt is not usually as broad as in February. This points out one of the features affecting the ice along the Labrador coast and in East Newfoundland waters. Offshore winds can spread the ice seaward, concentrations are lowered in the outer portions of the pack and shore leads can develop from White Bay to Cape Bauld and from Strait of Belle Isle northward to Hamilton Inlet. In these situations the pack streams seaward from Cape Freels and Fogo Island leaving the coast easily accessible from Cape Race to Bonavista Bay. On the other hand, onshore winds may narrow the pack considerably, some melting because of above zero temperatures may occur, mechanical destruction of ice by waves and swell can develop and deformation in the form of pressure ridges and hummocks become extensive. In periods such as these the major bays of East Newfoundland become filled with pack ice, the approaches to St. John's become congested and some ice may round Cape Race and drift towards the Burin Peninsula.

(b) **Patterns of Melting and Dispersal**

In April the rate of melting at the ice edge increases sufficiently to counterbalance the southward ice drift, and the slow retreat of the pack begins. It recedes to Cape Freels in the second week, then to Fogo Island at the end of the third week and at the same time the whole pack south of Hamilton Inlet becomes narrower because of melting along the eastern edge rather than as a result of onshore wind drift.

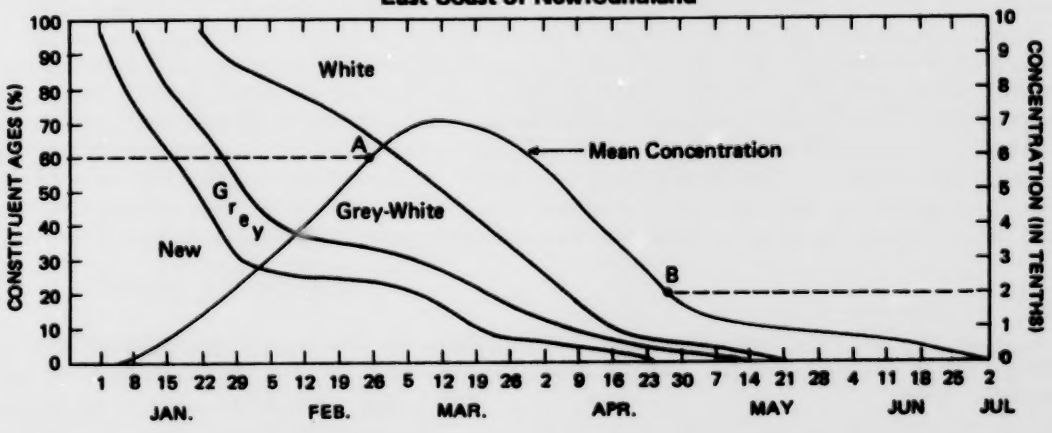
In May ice concentrations begin to drop although the median area of ice cover does not decrease appreciably. By mid month, navigation through the Strait of Belle Isle may become feasible although areas of close pack ice usually remain in the sector between St. Anthony and Twillingate. Near the end of the month, break-up of Lake Melville ice begins and clearing is usually accomplished in the first or second week of June. Navigation into the Lake may require penetration of the offshore ice pack unless offshore winds create a lead along the shore from Battle Harbour to Spotted Island, and to Groswater Bay. At this stage the ice pack tends to have very variable concentrations and east-west entry may be more prudent than "running the gauntlet" along the inner edge of the pack where a switch to onshore winds could present a serious hazard.

The median ice edge retreats to the mid Labrador coast during the third week of June, but in extreme years ice may linger south of Belle Isle as late as the first week in July. A continuous ice belt along the whole coast is not present however, in these situations.

(c) **Age Classes of Ice Present and Navigability of the Pack**

The east coast of Newfoundland is a special area as far as ice cover is concerned for the local temperature conditions cannot create ice of the thickness usually encountered. Advection of ice from more northern regions is the obvious explanation and this fact has a bearing on the proportions of the various age classes found in the pack.

East Coast of Newfoundland

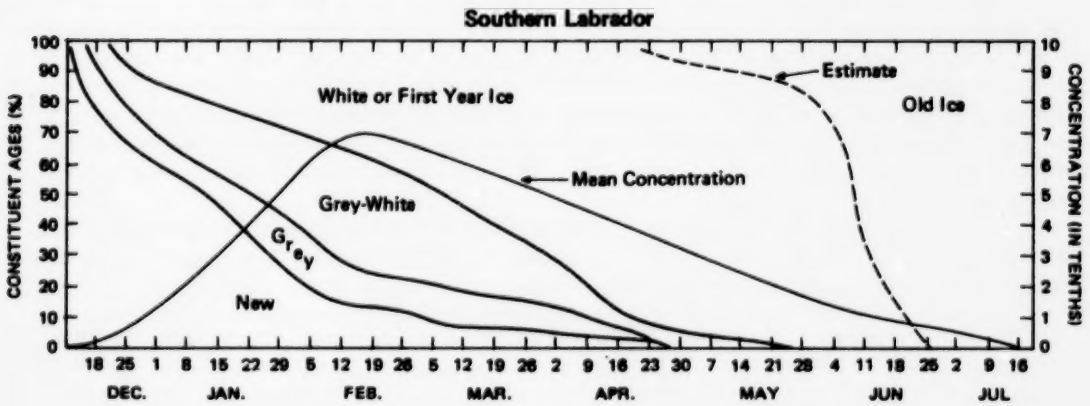


In Newfoundland waters three locations south of latitude 50°N were averaged for age class and concentration. The longer interval between ice formation and the appearance of white ice compared to that in the Gulf of St. Lawrence is a feature of the area. The open ocean to the east is a factor in this delay for it also affects air temperatures. A more important influence, however, is that average concentrations in the pack ice are somewhat lower than in an enclosed area such as the Gulf of St. Lawrence. East of Newfoundland the pack can be dispersed seaward and concentrations may drop to the 6-7 tenth range. (The NOAA-4 imagery Figure 1 is an example). On the other hand, protracted onshore winds may compress the pack along the coast leaving the offshore area clear of ice.

One factor which is difficult to represent graphically is that a few percent of old floes may appear in the pack in Notre Dame Bay. This ice arrives in late spring, it is the last to melt, and is very rare in waters south of Cape Freels. It is not shown on the graph for this reason.

Seasonal navigability by vessels can be estimated as before if the ice concentration and age limitations are specified. For example, a ship which can operate in six tenths of ice providing no more than two tenths of it is white ice (33%) could be expected to penetrate the ice in this area until 26 February and could recommence its routes on 30 April. These dates are marked as A and B on the graph.

In southern Labrador waters four locations have been averaged to produce the following graph. In this area the delay in formation of white ice is much less but the concentration maximum is much the same as in Newfoundland waters. The rate of decreased concentration during the spring is much slower of course because of the increase in latitude and the greater thickness of the ice.



The occurrence of old ice is somewhat more common and a proportion is shown beginning in April. It does not reach significant proportions until the latter part of May when much of the thinner ice has melted and average concentrations are low. In cold years however, when more ice is present, these old floes can have a serious limiting effect on navigation. It should be pointed out that actually averaging of small intrusions of ice of this nature is not possible with the limited data on hand. The curve shown for old ice is therefore an estimate as far as the details are concerned although the basic starting date, the fact that proportions are under one tenth for most of the spring, and the clearing dates can all be verified.

(d) Features of the Area

(i) The mean wind flow in the Strait of Belle Isle area is from the northwest during the winter, but in April a trough line from the south of Cape Farewell to the Bay of Fundy gives a mean northeast wind.

DATES WHEN STRAIT OF BELLE ISLE BECAME NAVIGABLE

	With Very Open Pack Ice in the Approaches	Bergy Water – no sea ice but bergs are present
1958	May 14	May 21
1959	June 18	June 25
1960	June 18	June 30
1961	May 24	May 30
1962	June 18	June 23
1963	May 21	June 11
1964	June 4	June 11
1965	June 11	June 15
1966	May 20	May 24
1967	May 15	May 24
1968	June 4	June 15
1969	May 23	June 1
1970	July 2	July 4
1971	June 11	June 15
1972	July 2	July 12
1973	June 1	June 8
1974	July 11	July 16
1975	June 30	July 4
Median*	June 8	June 16

*In the 14 years 1945-1958 inclusive, opening dates reported by International Ice Patrol ranged from May 2 in 1951 to July 15 in 1957 with a median of June 1. Ice conditions at the time of the opening were not specified.

In periods when these northeast winds develop some of the ice from the Labrador coast can be driven through the Strait of Belle Isle and into the northeast arm of the Gulf. In 1966 ice from this source drifted as far as Cape Whittle. One of the prerequisites, appears to be that little ice remains within the Gulf when this influx develops, and one of the consequences is that small bergs may be pushed through the strait with the pack ice. Because this ice from the Labrador coast is thicker than that formed locally, clearing in the strait is slow when these intrusions occur.

(ii) Water currents in the Baffin Bay – Davis Strait – Labrador coastal areas are generally in the range of 5-7 nautical miles per day. As a result, even without wind-induced drift, ice can be carried southward by about three degrees of latitude per month and from November until April, ice may drift from the mid Baffin coast down into Notre Dame Bay. It is apparent that after summers when Baffin Bay does not clear completely, the risk of very thick, hard old ice floes occurring in Newfoundland waters the following spring are greater than in normal years. Wind drift is an additional factor, of course, for the old floes may be carried to the outer edge of the pack and into warmer waters where they can melt before reaching southern Labrador or their drift may be retarded by the wind so that the total transport distance is much reduced. The spring of 1973 provides an example of old ice intruding into Newfoundland waters after a summer of incomplete clearing of Baffin Bay. 1974 and 1975 were years when the wind-induced drift aided the southward transport of old ice from Smith Sound (Latitude 77°N) to reach Newfoundland before melting even though Baffin Bay had cleared the previous summers. In 1976 the only old ice to pass Hamilton Inlet was in the outer edge of the pack and none of it reached the Notre Dame Bay area before melting.

(iii) Icebergs which affect navigation in this area are discussed in the following chapter.

C. MEDIAN ICE CHARTS

The following charts depict the median ice concentrations on the Eastern Canadian Seaboard during the years 1963-1973; the minimum and maximum ice limits and an indication of the number of times that ice has occurred in each area.

The lines of the median ice edges were drawn from the computer out-put mentioned on page 5, and do not represent actual conditions at any one time. The Extreme Ice Limits on the other hand have been related to actual conditions in that the edge shown is a composite of all ice intrusions during the eleven year study period. Although the data has not all been digitized and computer analyzed, ice charts for the 18 year interval 1958 - 1975 are in the records, and extreme ice limits for these longer periods are shown by the broken ice limit lines. The frequency of occurrence of these additional areas of ice has not yet been processed.

Eleven or even eighteen years of data are very limited samples if a statistical treatment of ice occurrence is to be attempted. Since ice occurrences are closely related to air temperature it is pertinent to examine the meteorological records for the area in order to assess where the eleven year interval being studied falls in relation to the longer period averages. At five stations between Quebec City and Cabot Strait and four stations from St. John's to the central Labrador coast, the eleven years represent winters when there were from 50 to 100 more freezing degree-days accumulated than the 20 year normal going back to 1953.

Halifax has a continuous meteorological record going back to 1874 and at St. John's the data record is similar although there are some interruptions in the 1920's and 1930's. For the winter months, December 1 to March 31 at Halifax, the 100 year means are all within 0.3°C of the means during the 11 year study period. The difference in the short term represents an increase of only 25 freezing degree-days over the 100 year average. This is not an insignificant figure for it is about 7% of the winter accumulation at Halifax but it is certainly small.

At St. John's the 11 year study period is warmer than the 100 year average (actually 93 years of record) by 0.3°C each month for a total freezing degree-day variation of 30. Again this is 7-8% of the normal winter accumulation but in this case it is a decrease.

On the basis of the above it is considered that although the study period is short, the median conditions presented are truly representative of the ice one should expect. There may be variations in the extreme limits from those encountered since 1958 but even these should be small.

Following the median charts are five examples of actual conditions in the areas as reported by aerial reconnaissance. The first two represent mild and severe conditions in the Gulf in mid March. The third is an example of conditions during a protracted period on onshore winds in east Newfoundland; the fourth shows the location of the pack at a similar date following a period of offshore winds. The fifth chart is an example of severe ice conditions in northern Newfoundland when old ice intrudes. In a "good" year, the entire area to latitude 55°N would be open water on this date.

LEGEND

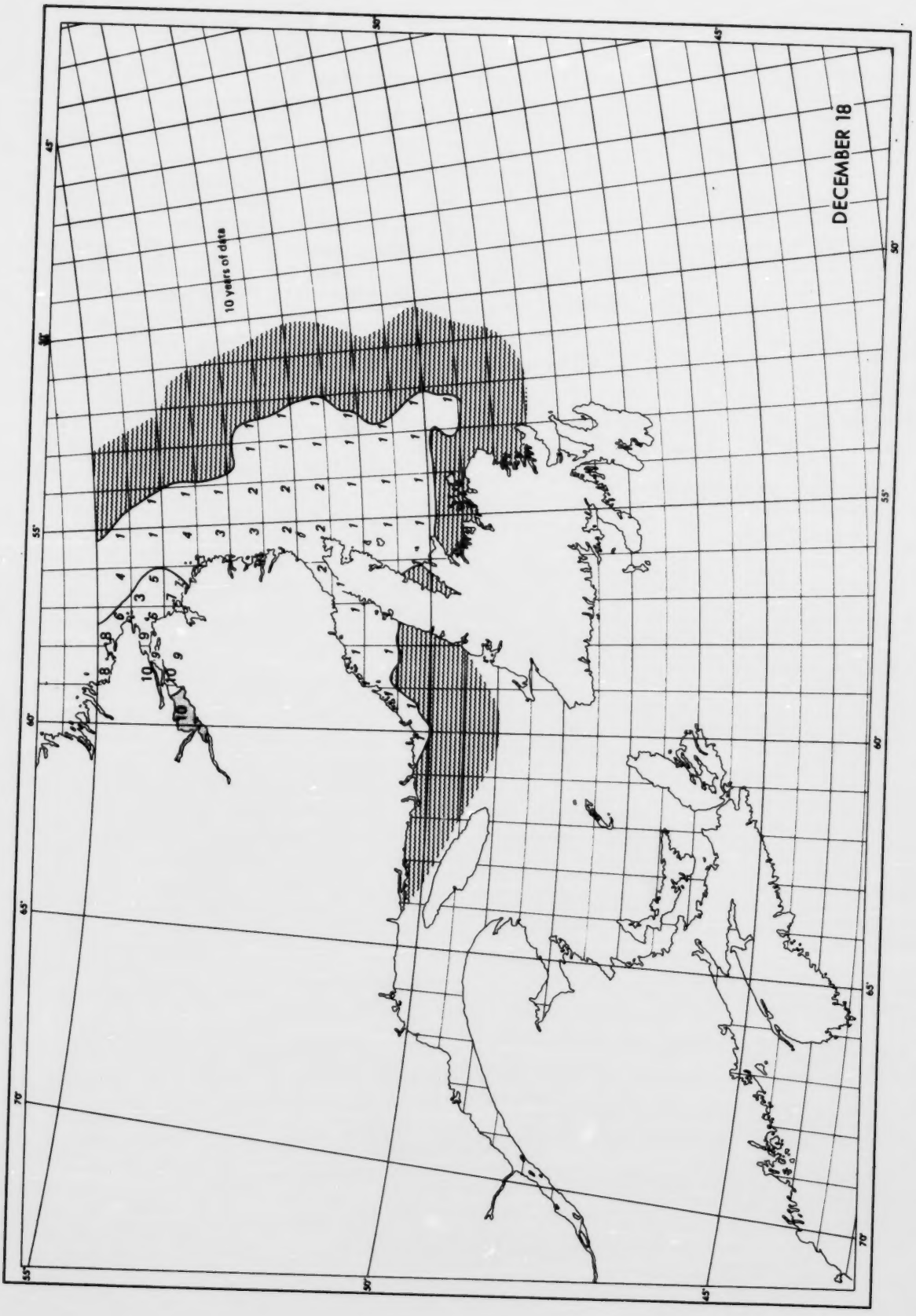
On the charts which follow, the extreme and median position of the ice edge (for years 1963-1973) is shown as follows:

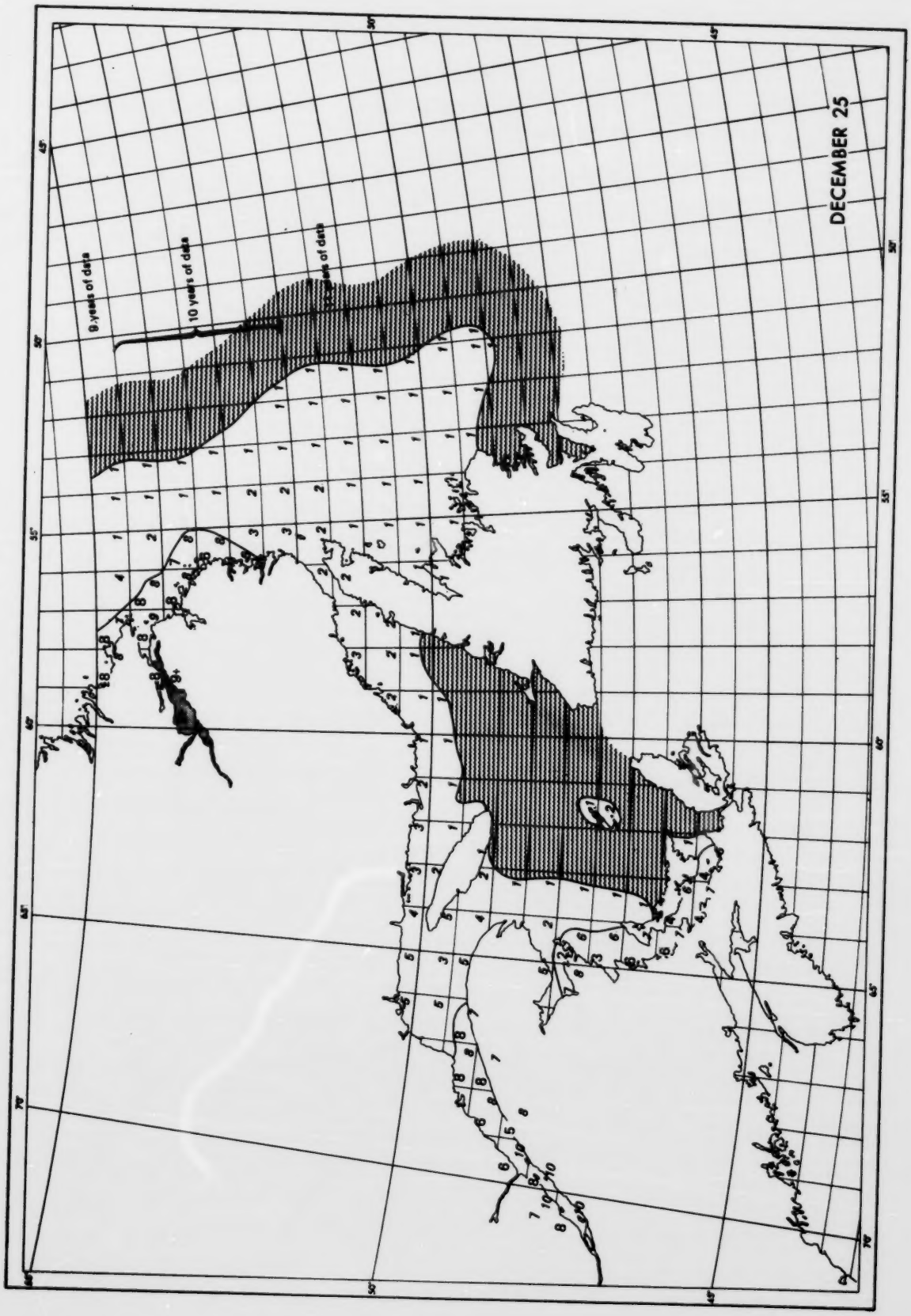
Extreme Maximum Limit– defined by ripple outline
Median Limit– black line
Extreme Minimum Limit– defined by grey stipple

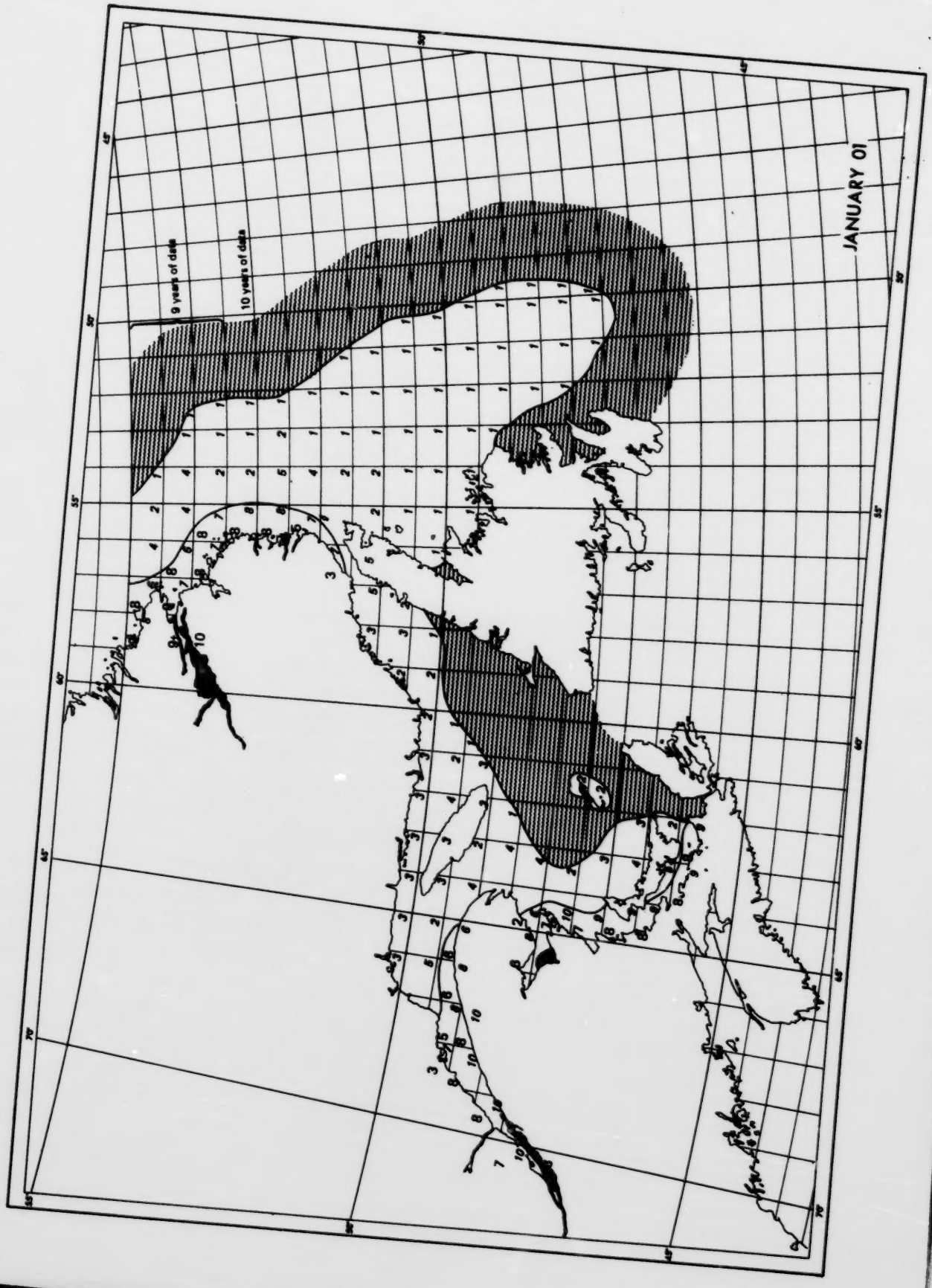
Between the maximum and median positions, the number of years that ice was present (out of 11) is shown by oblique digits in lower right of each square. Changes in the extreme limit caused by the spring ice conditions of 1973 are shown as dashed lines.

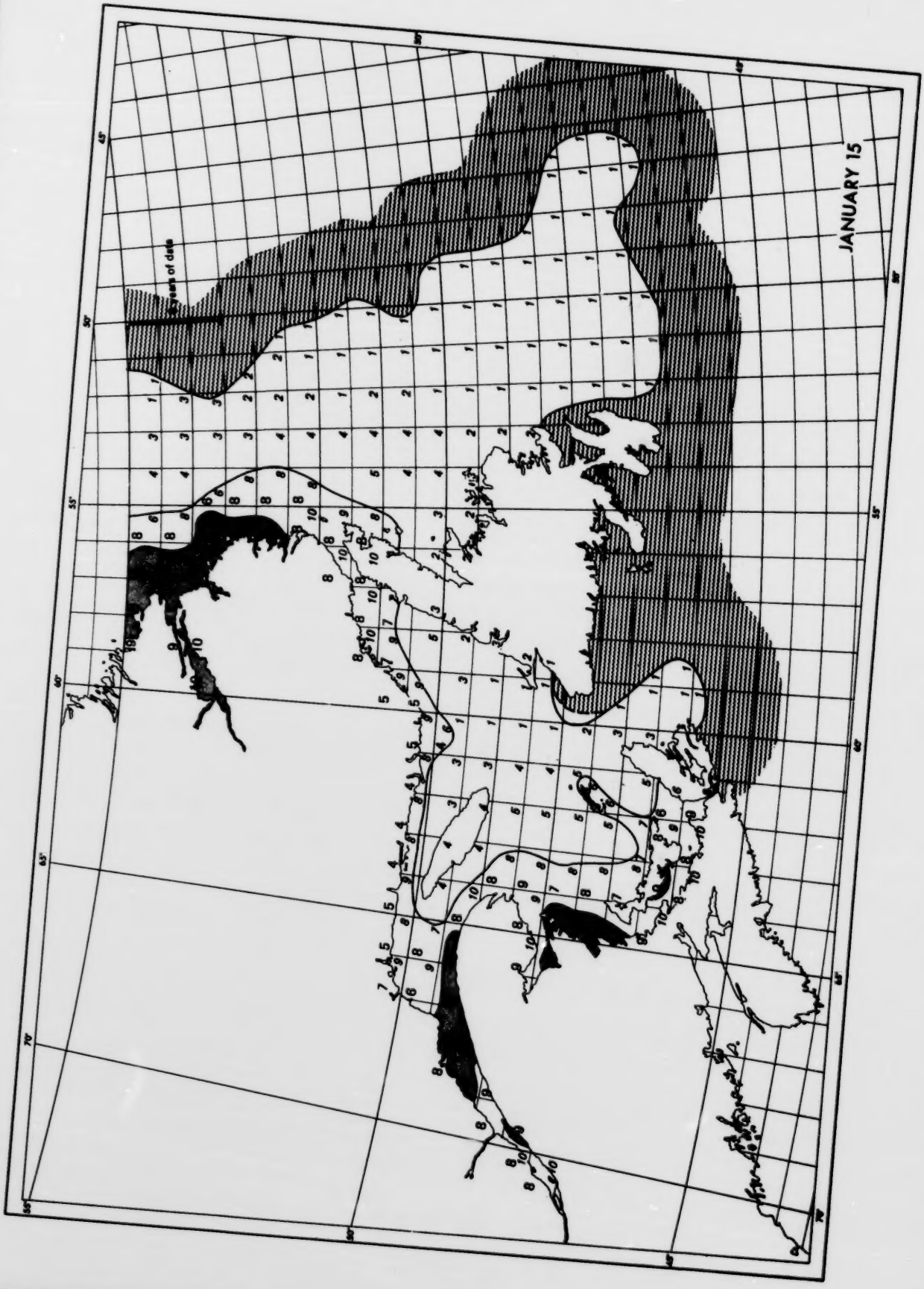
Between the median and minimum lines, the median total concentration is shown by vertical digits in the upper left of each square, and the number of years that ice was present is given by a smaller oblique digit in the lower right. 6_8 6 tenths is median concentration and ice was present in 8 years out of 11.

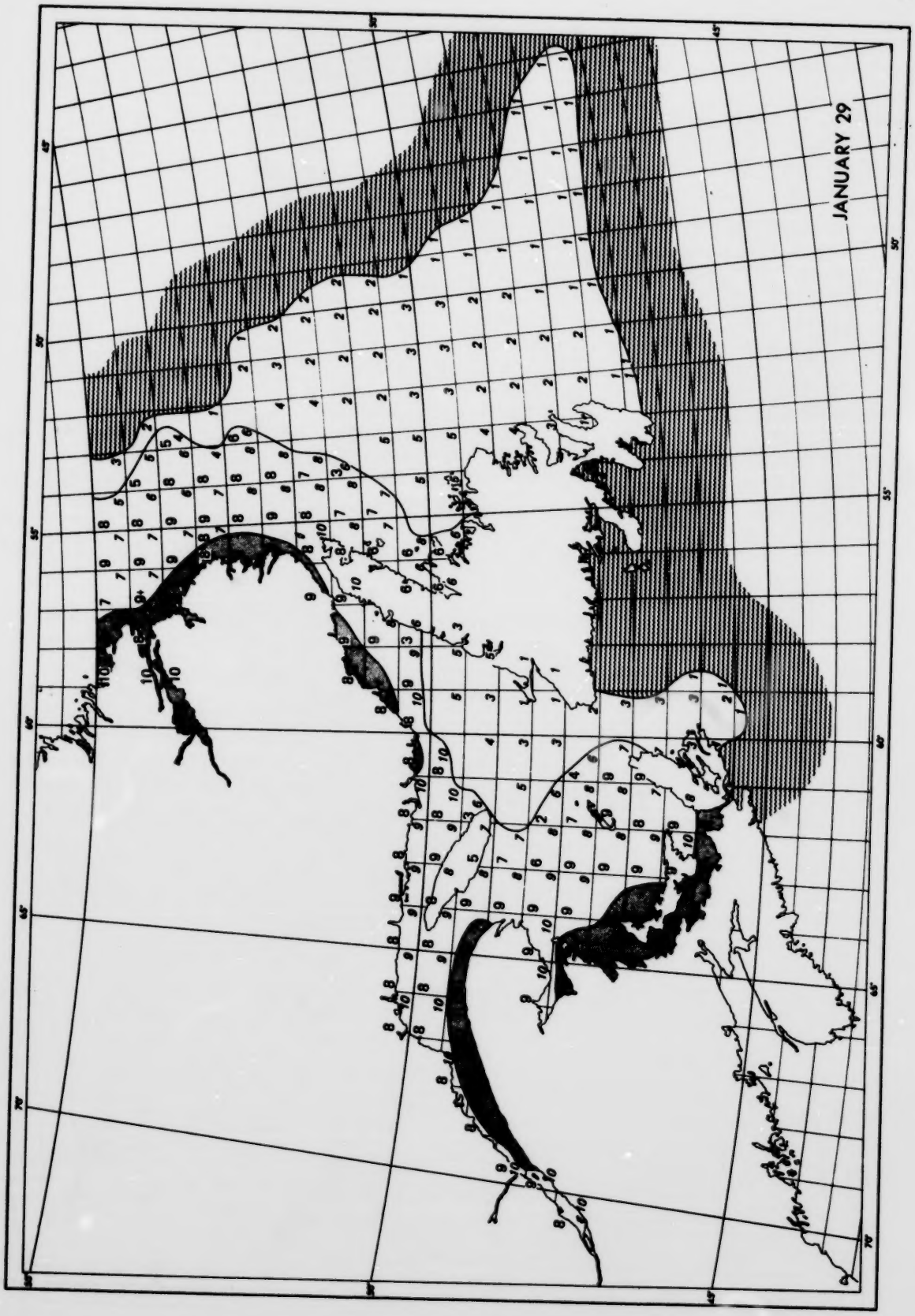
Within the minimum limit line, only the median concentration is given. The years that ice was present is always equal to the number of years of data, i.e. 11 in the Gulf of St. Lawrence, but sometimes as low as 9 on the Labrador coast.

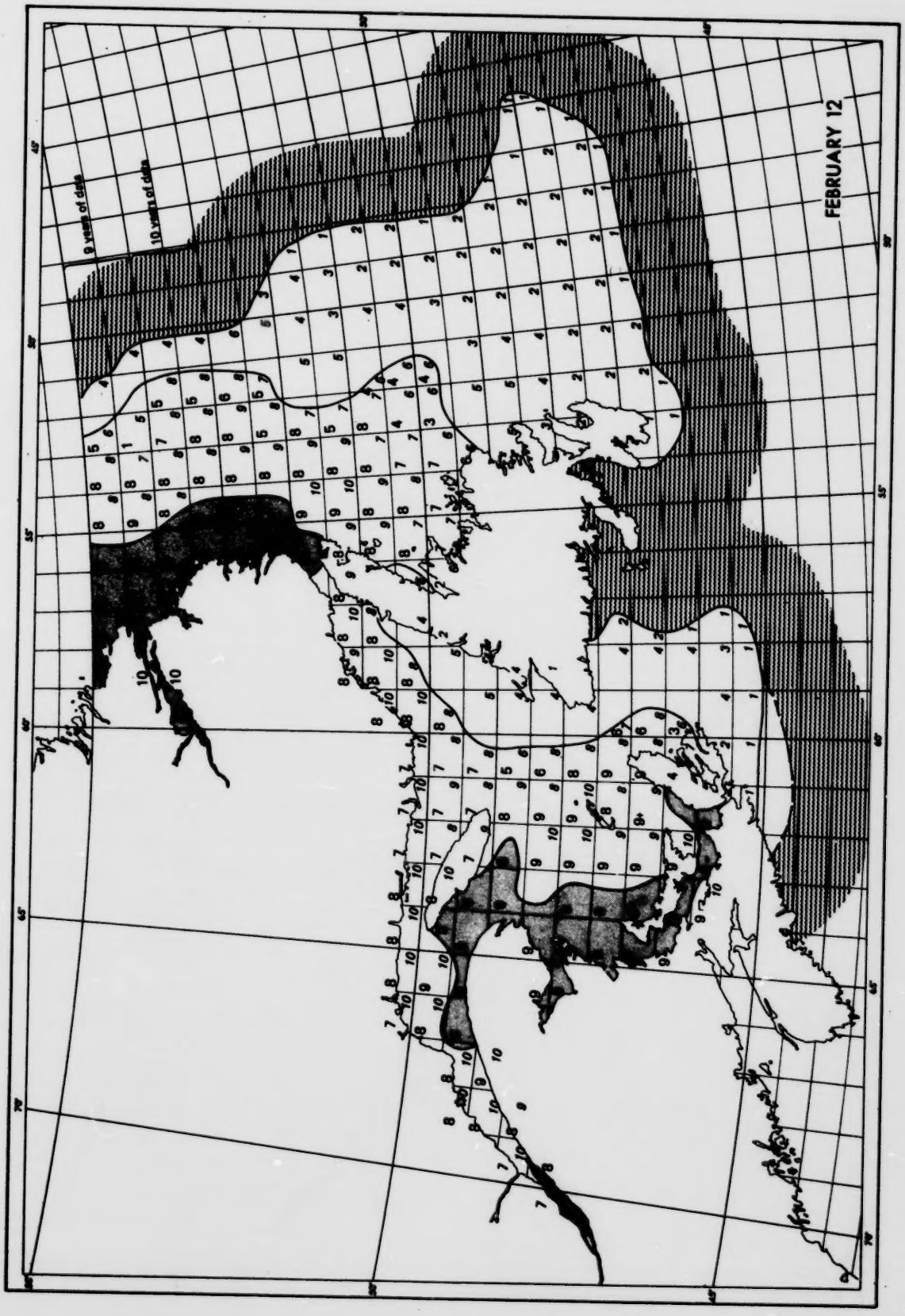

DECEMBER 18
10 years of data
55°
50°
45°
60°
65°
70°

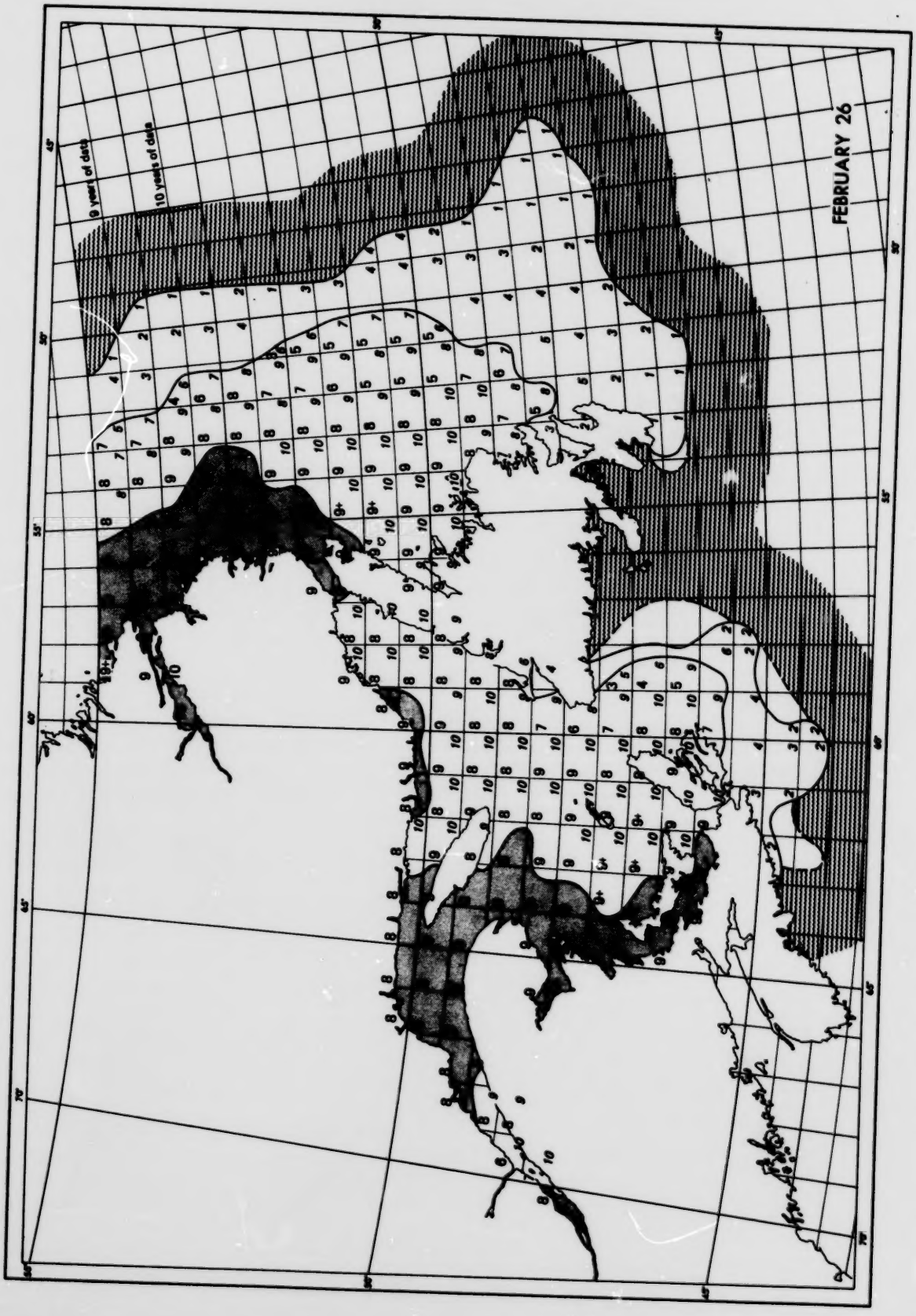

DECEMBER 25
8 years of data
10 years of data
12 years of data

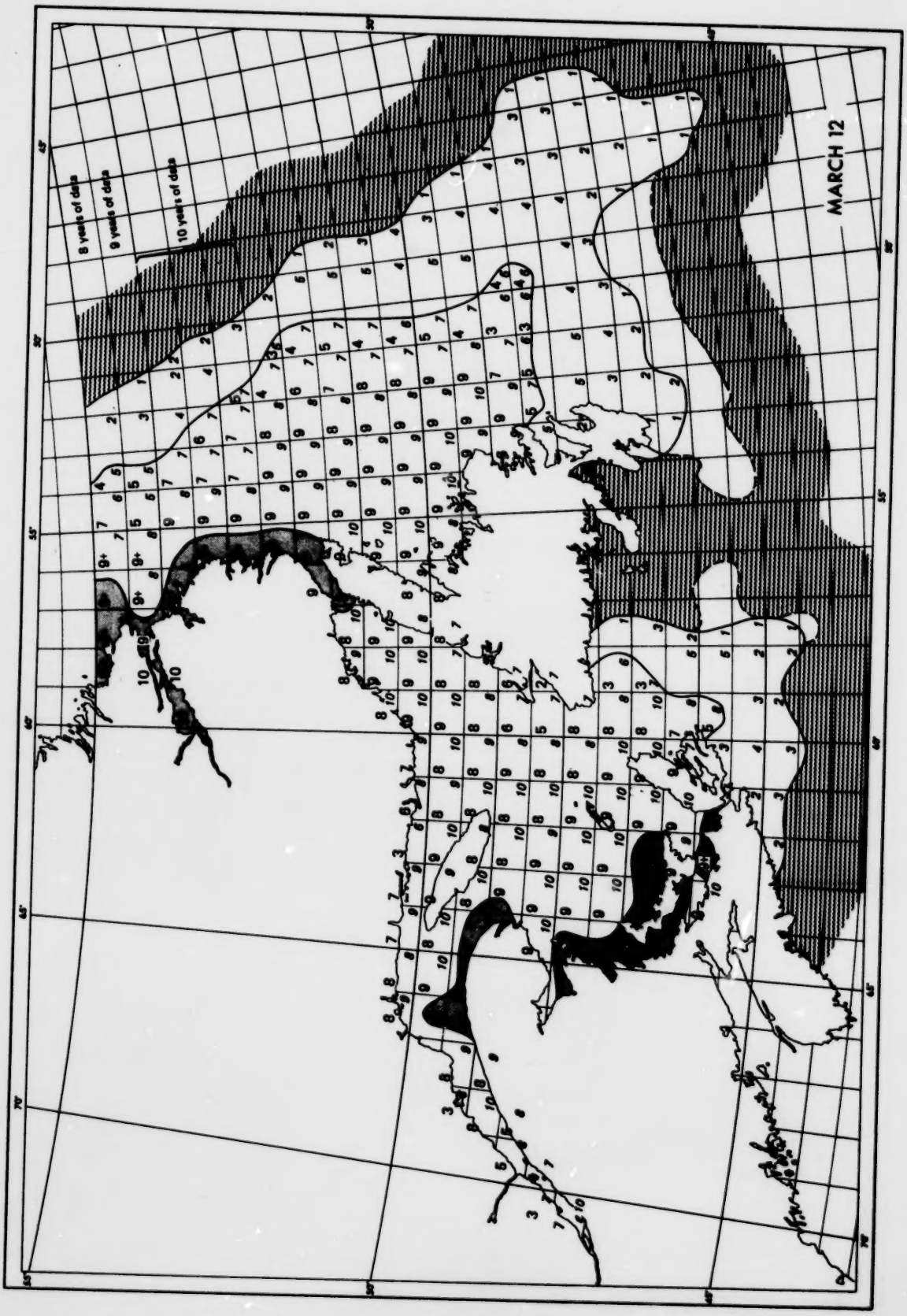

JANUARY 01
9 years of data
10 years of data

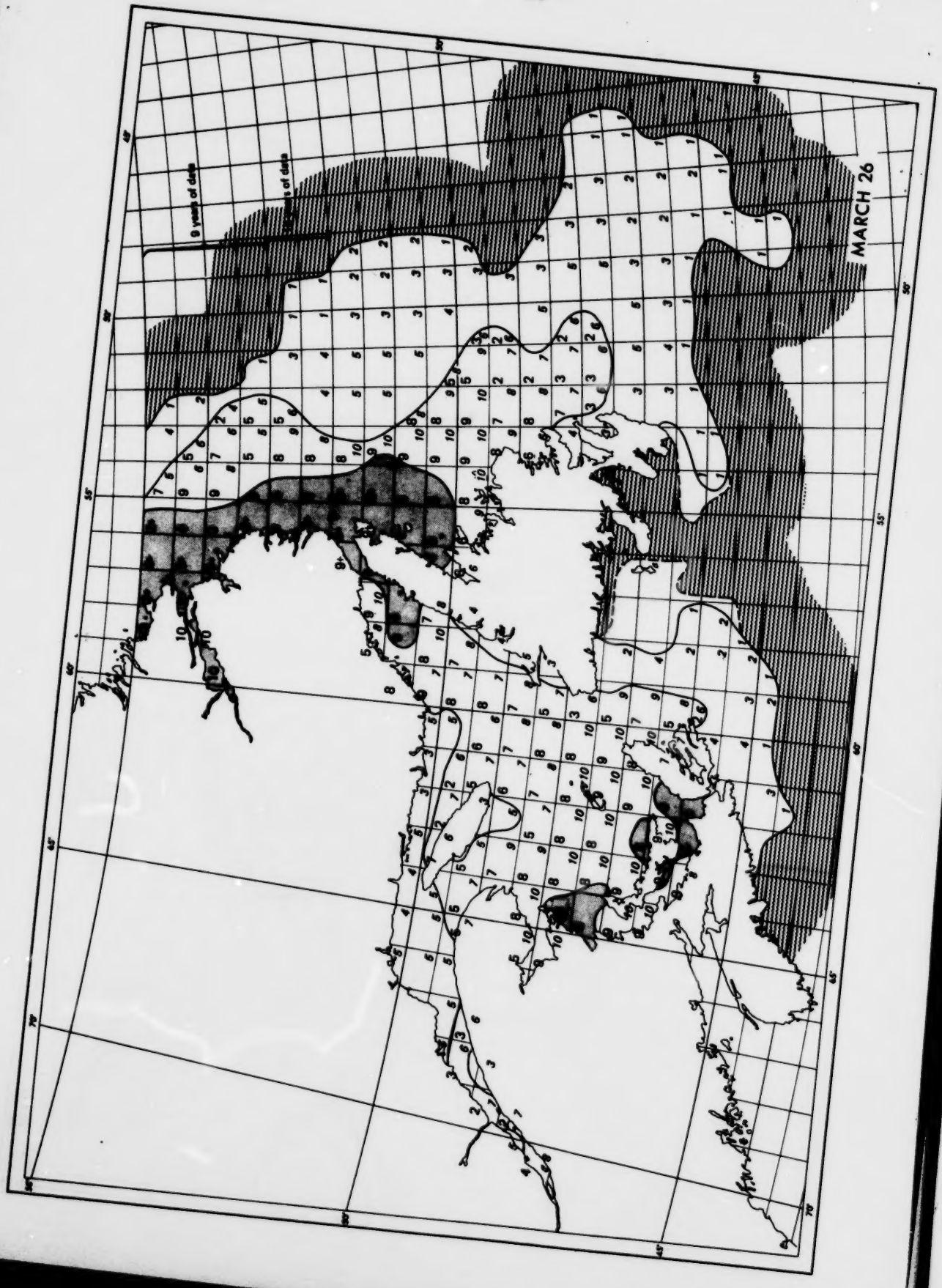

JANUARY 15
Years of data

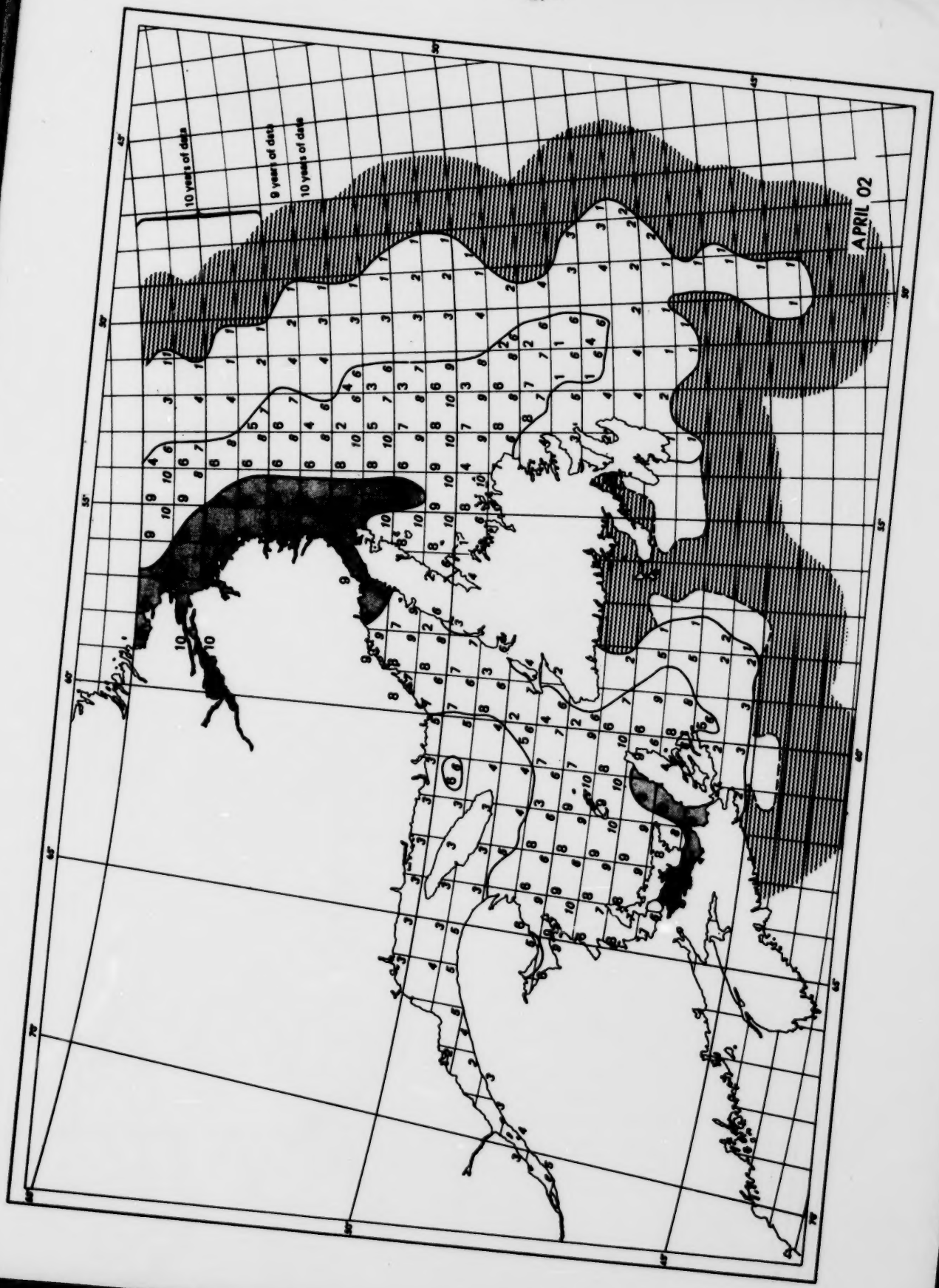

JANUARY 29

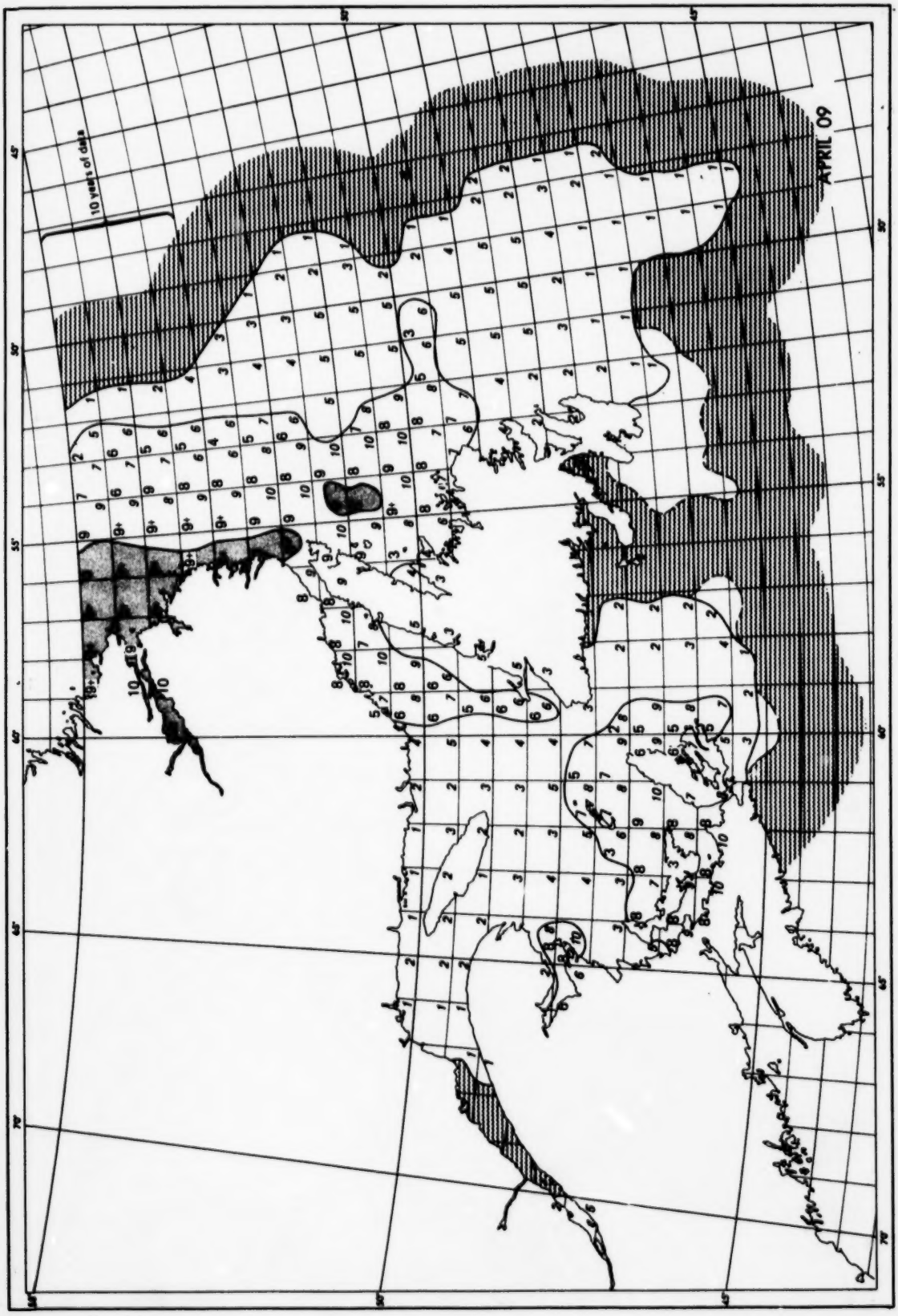

9 years of data
10 years of data
FEBRUARY 12

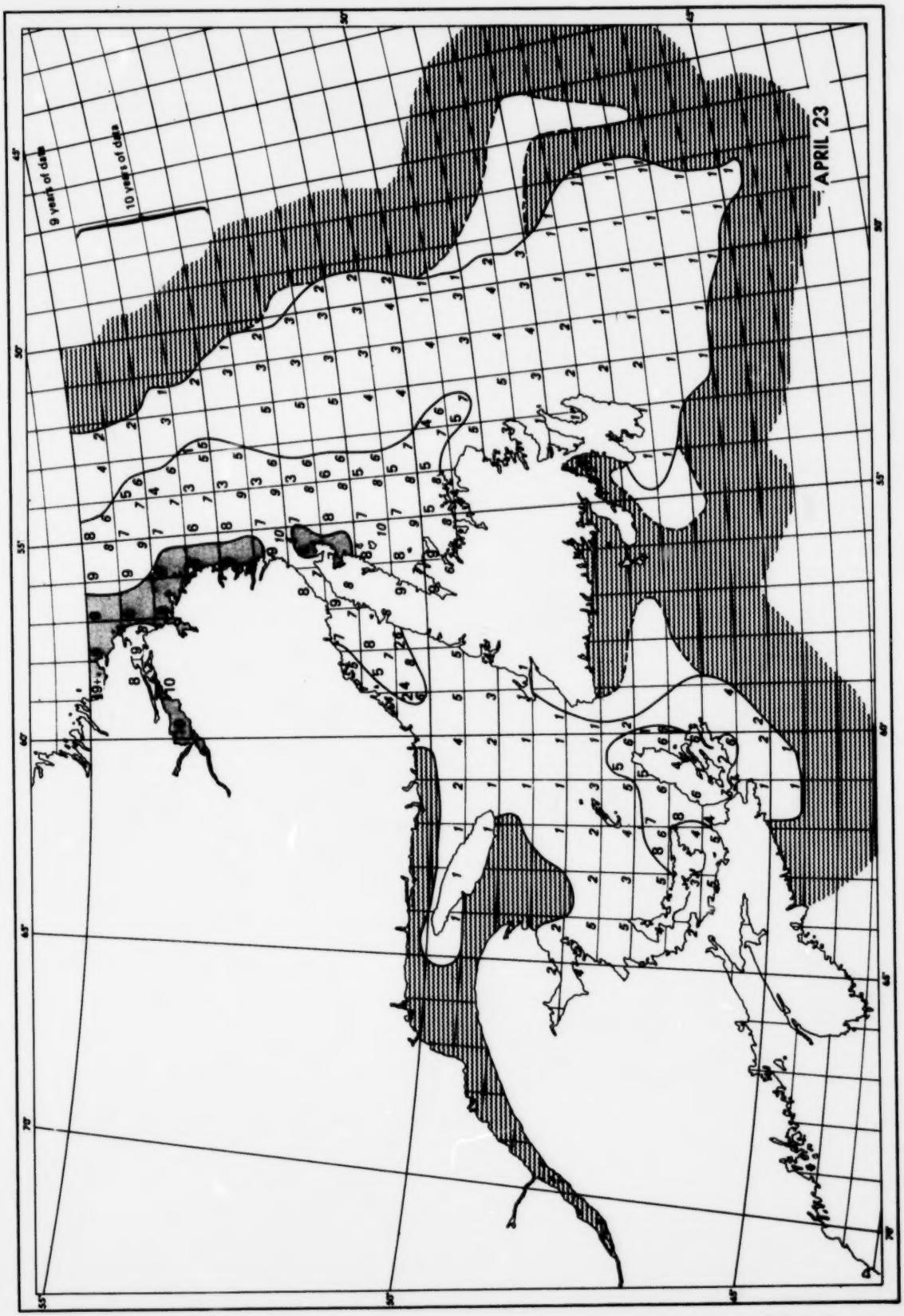

9 years of data
10 years of data
FEBRUARY 26

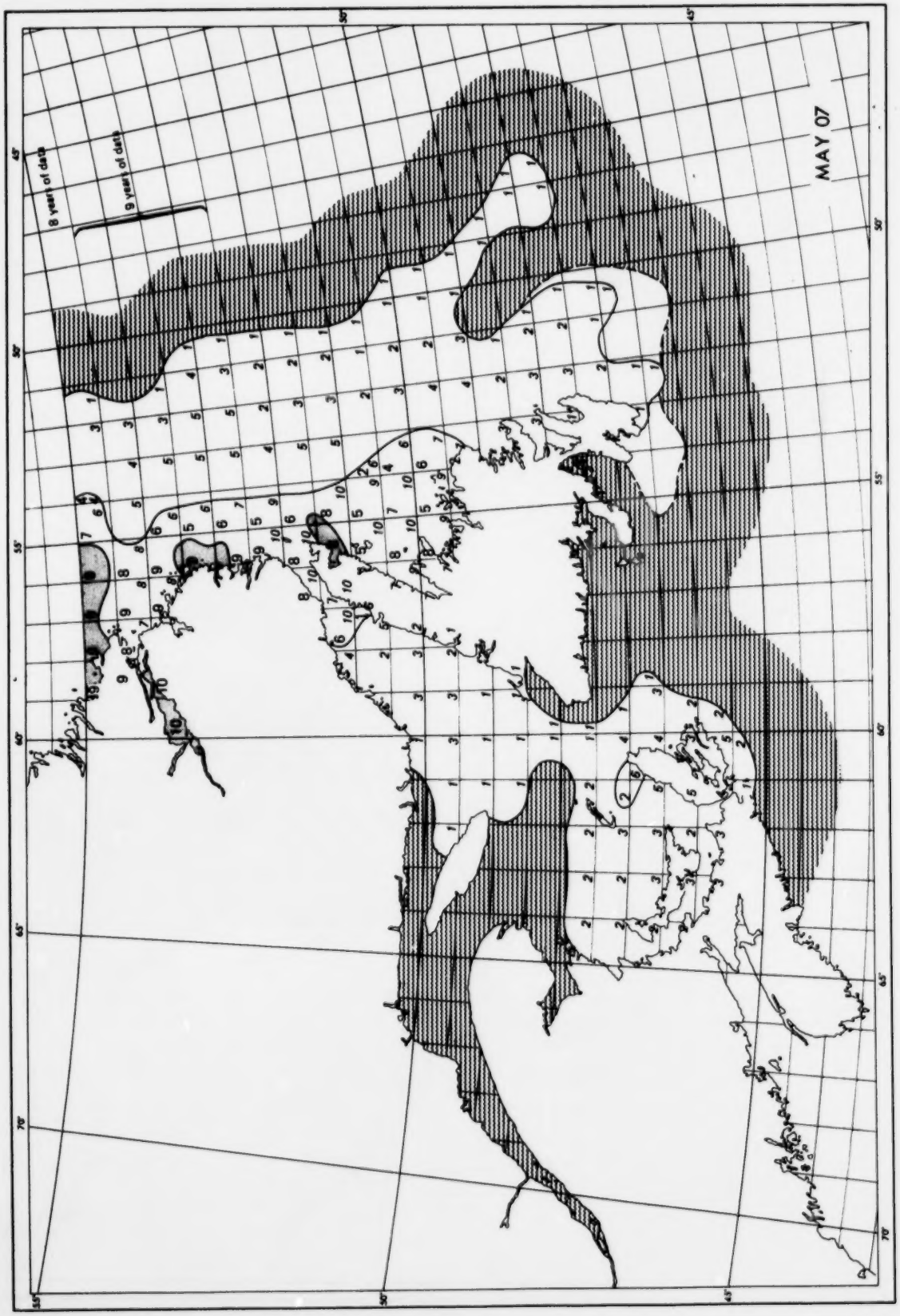

MARCH 12
8 years of data
9 years of data
10 years of data

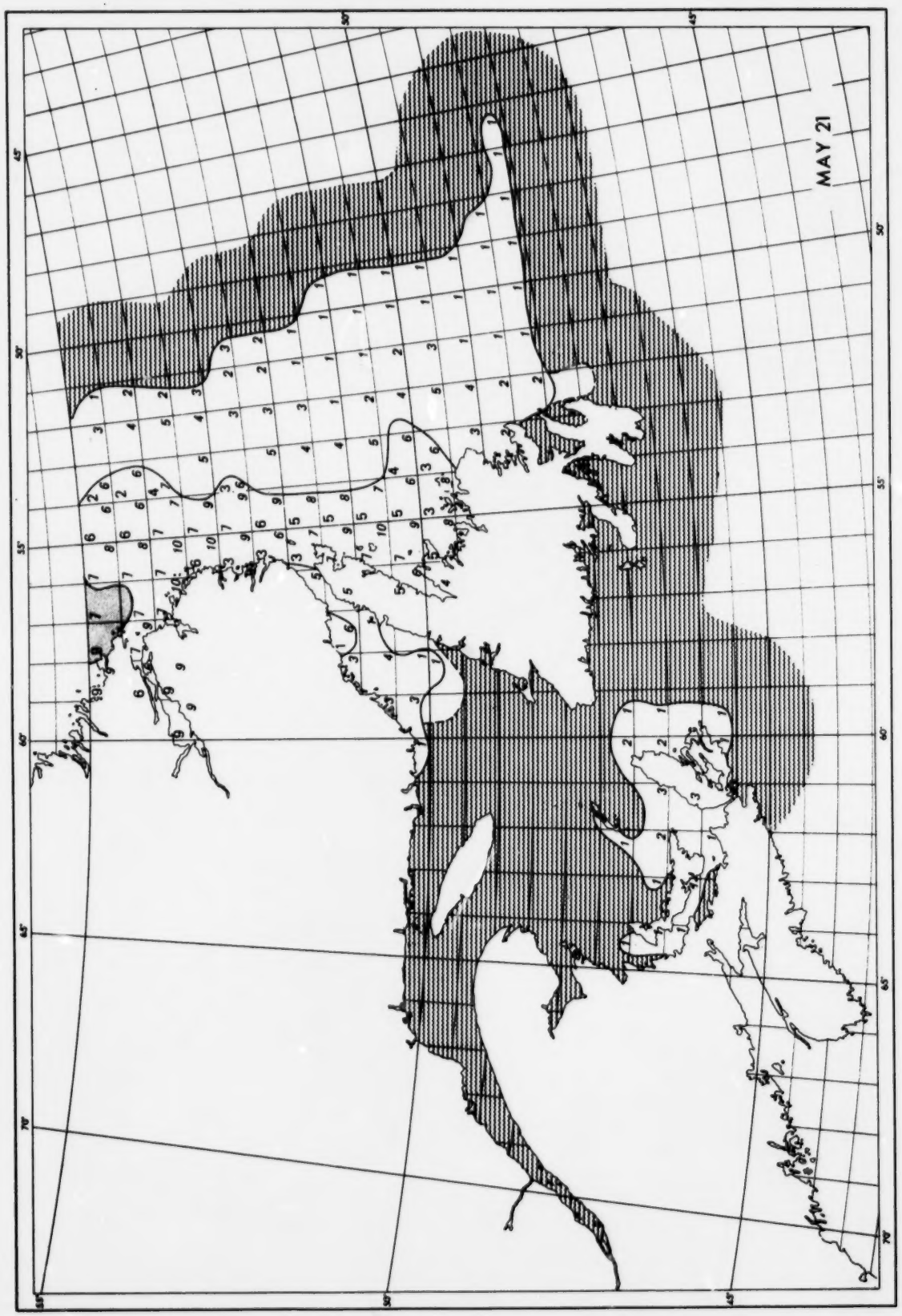

MARCH 26
9 years of data
5 years of data


10 years of data
9 years of data
10 years of data
APRIL 02


10 years of data
APRIL 09


APRIL 23
9 years of data
10 years of data


MAY 07
8 years of data
9 years of data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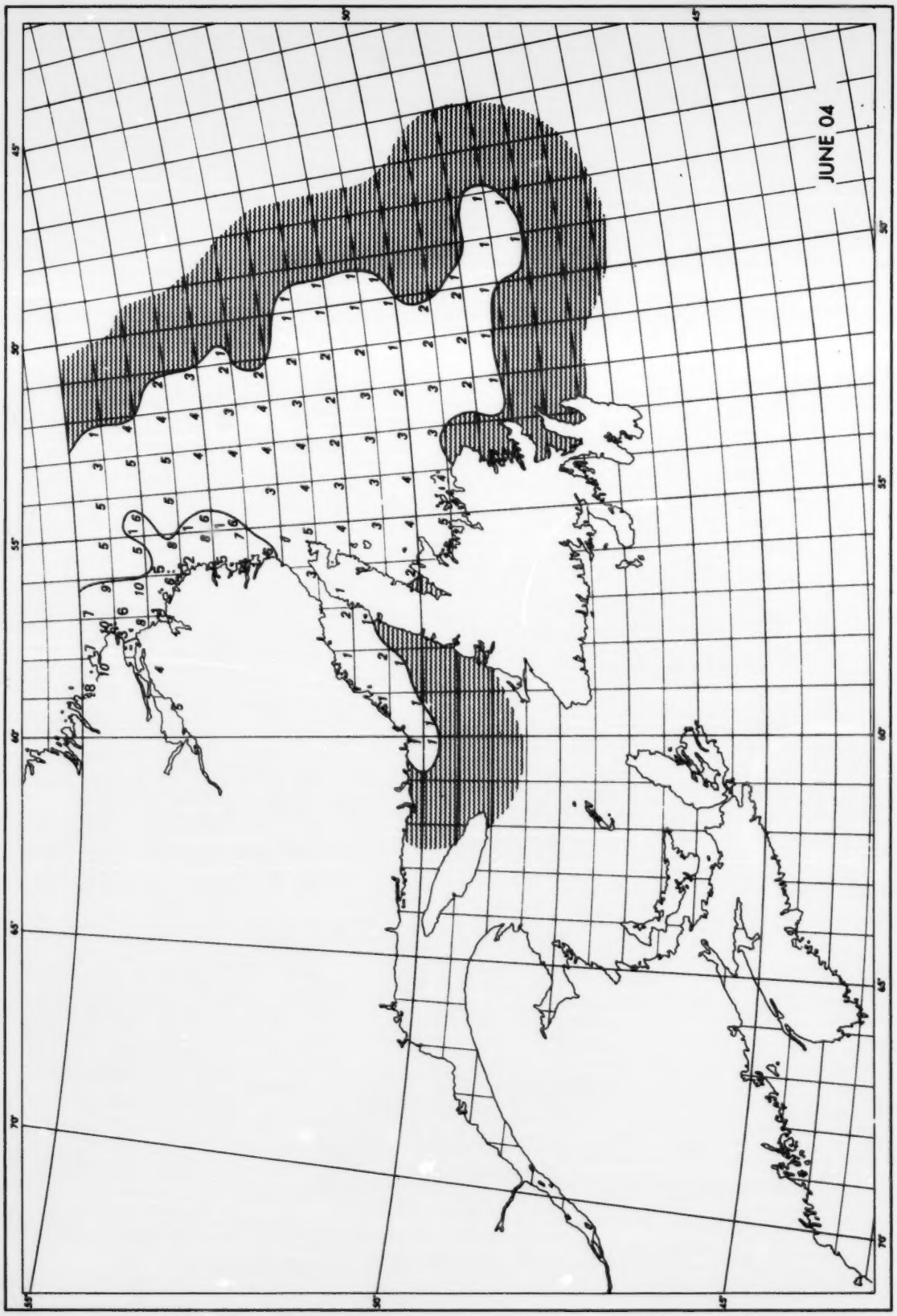
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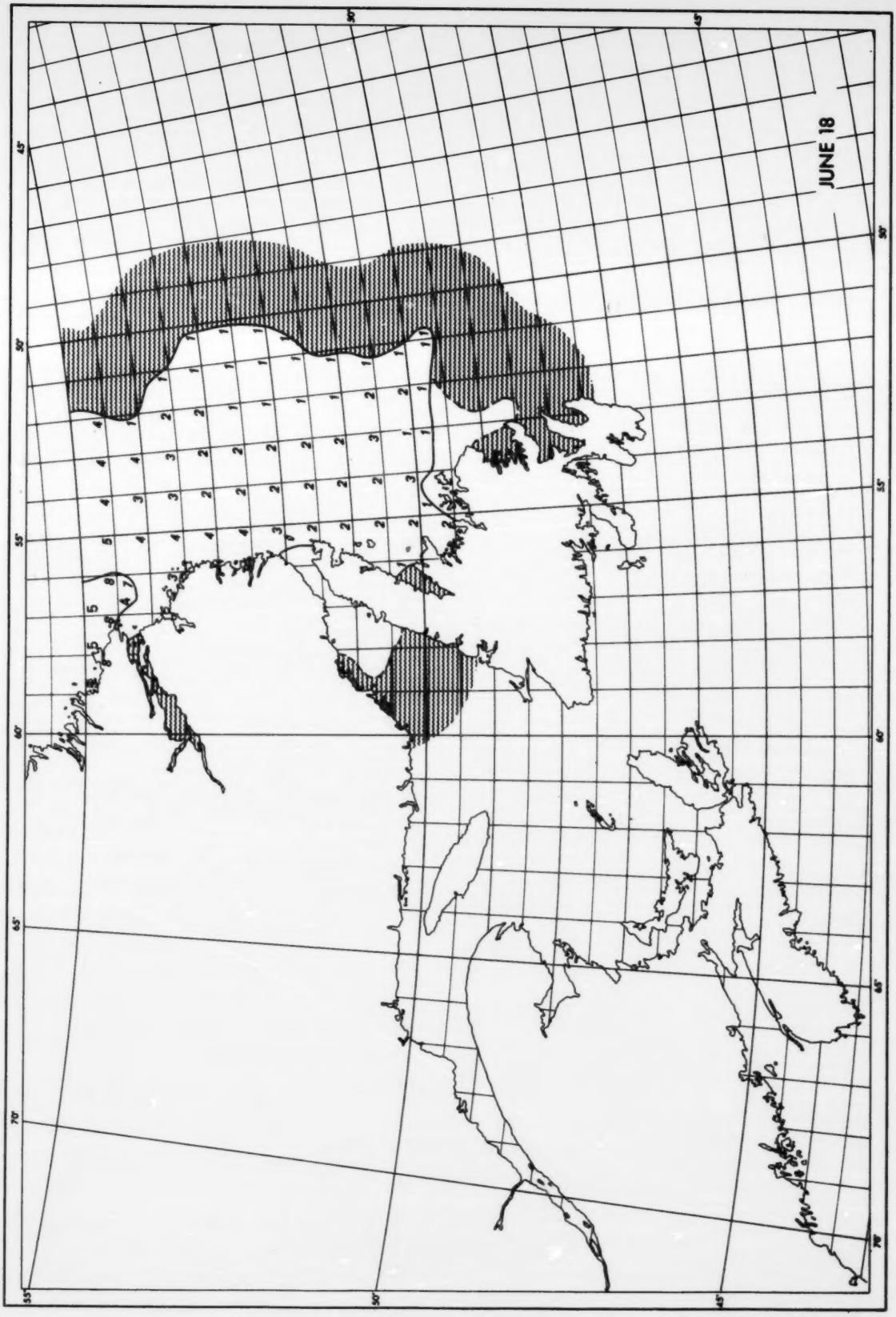
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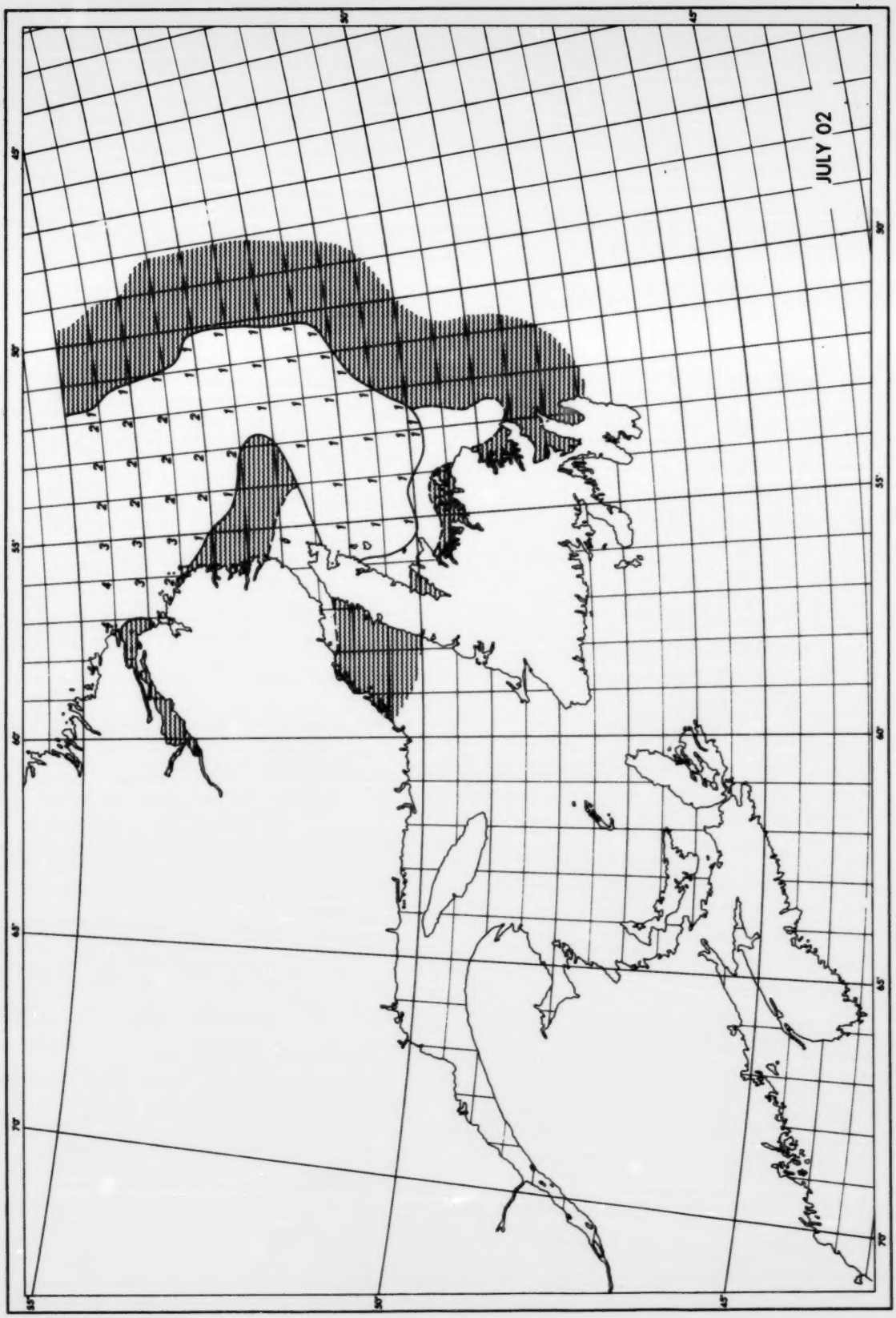
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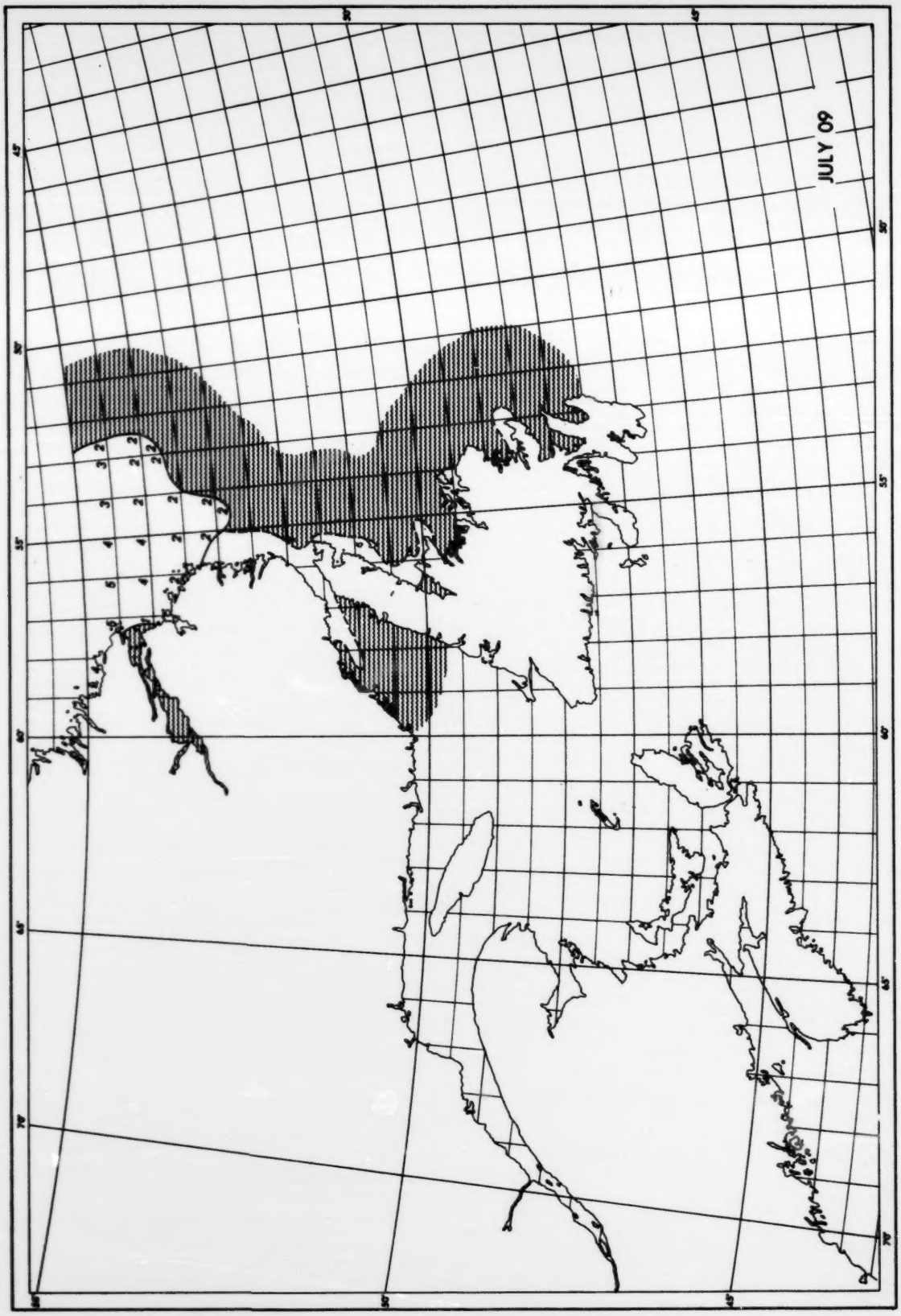
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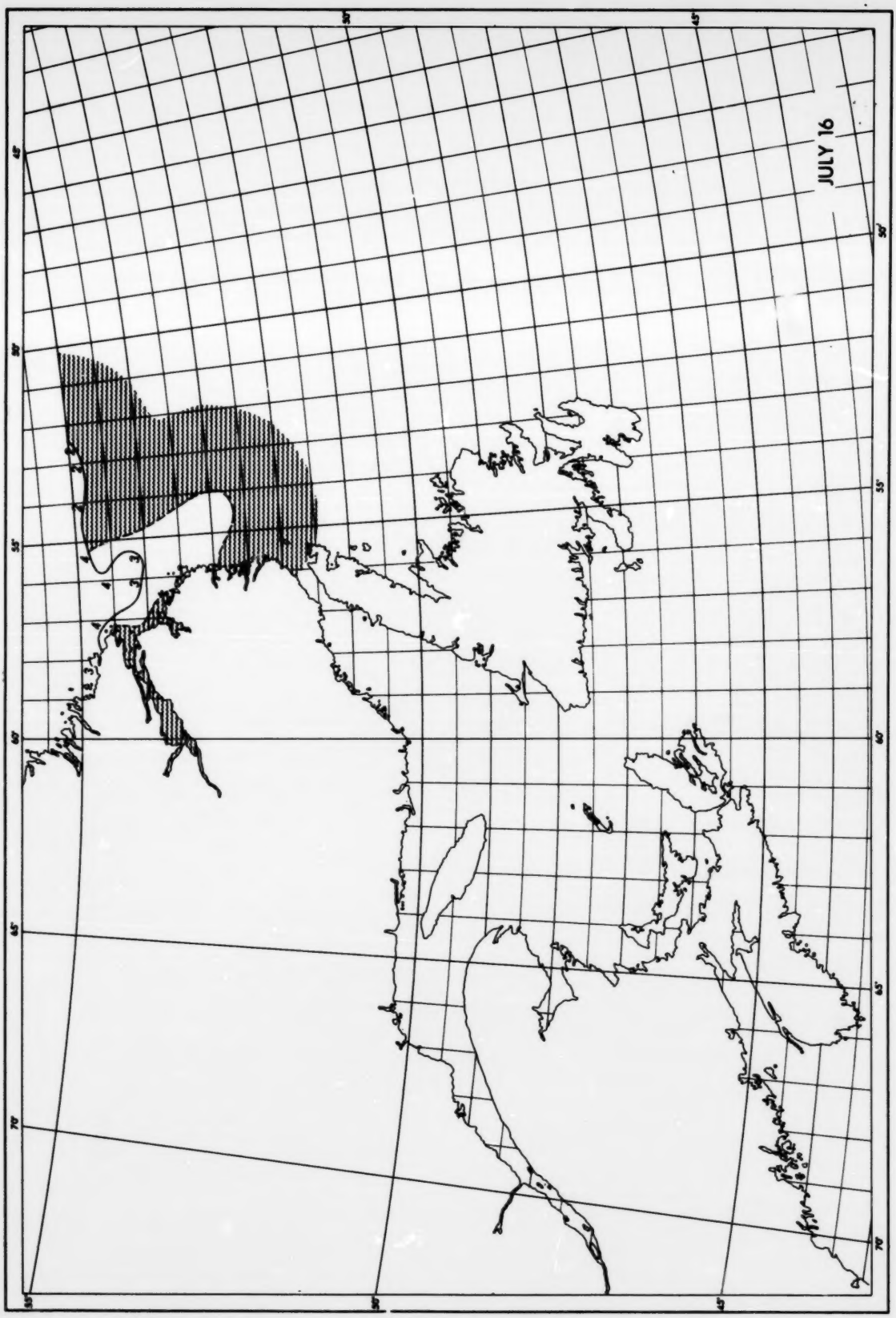
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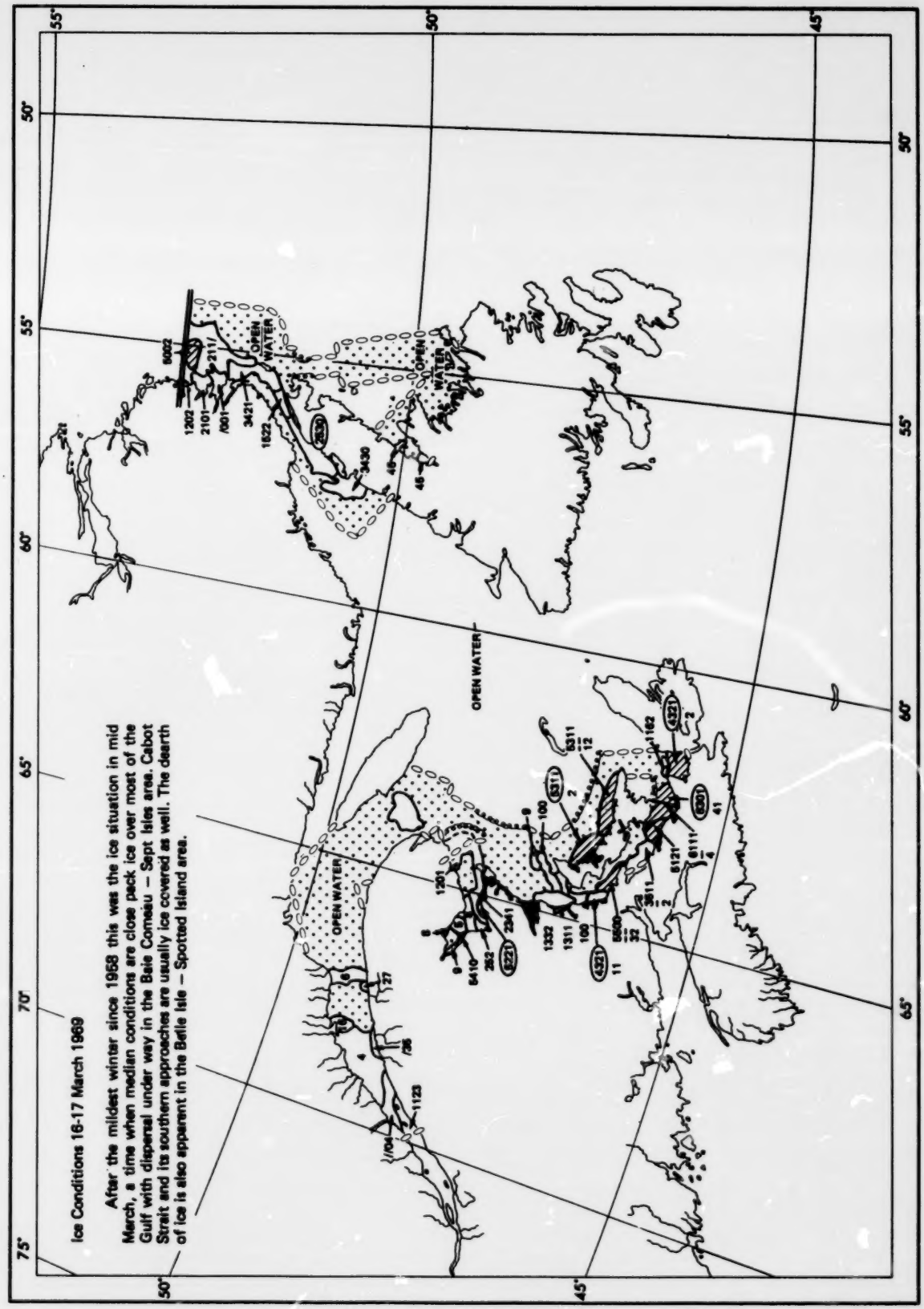
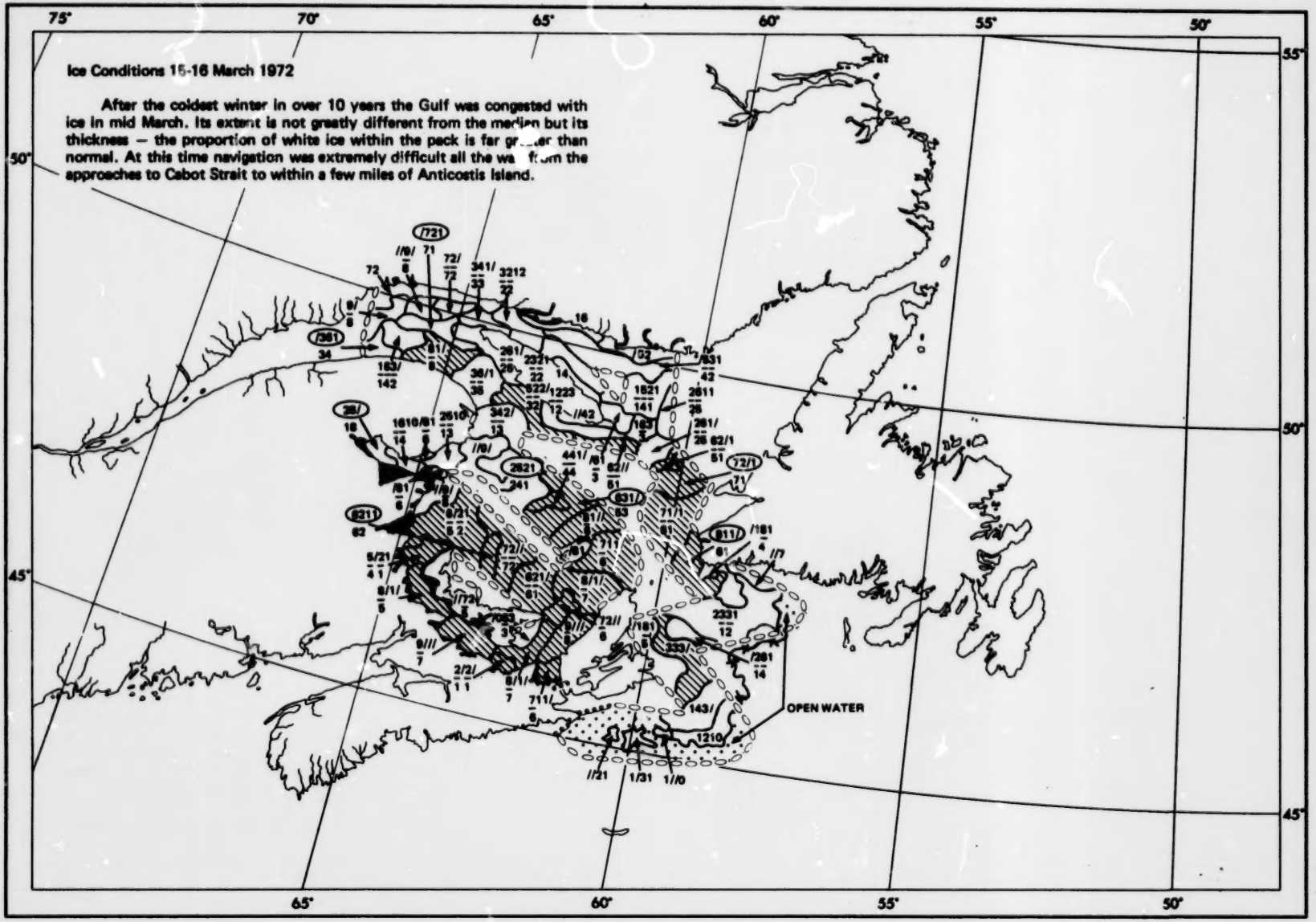
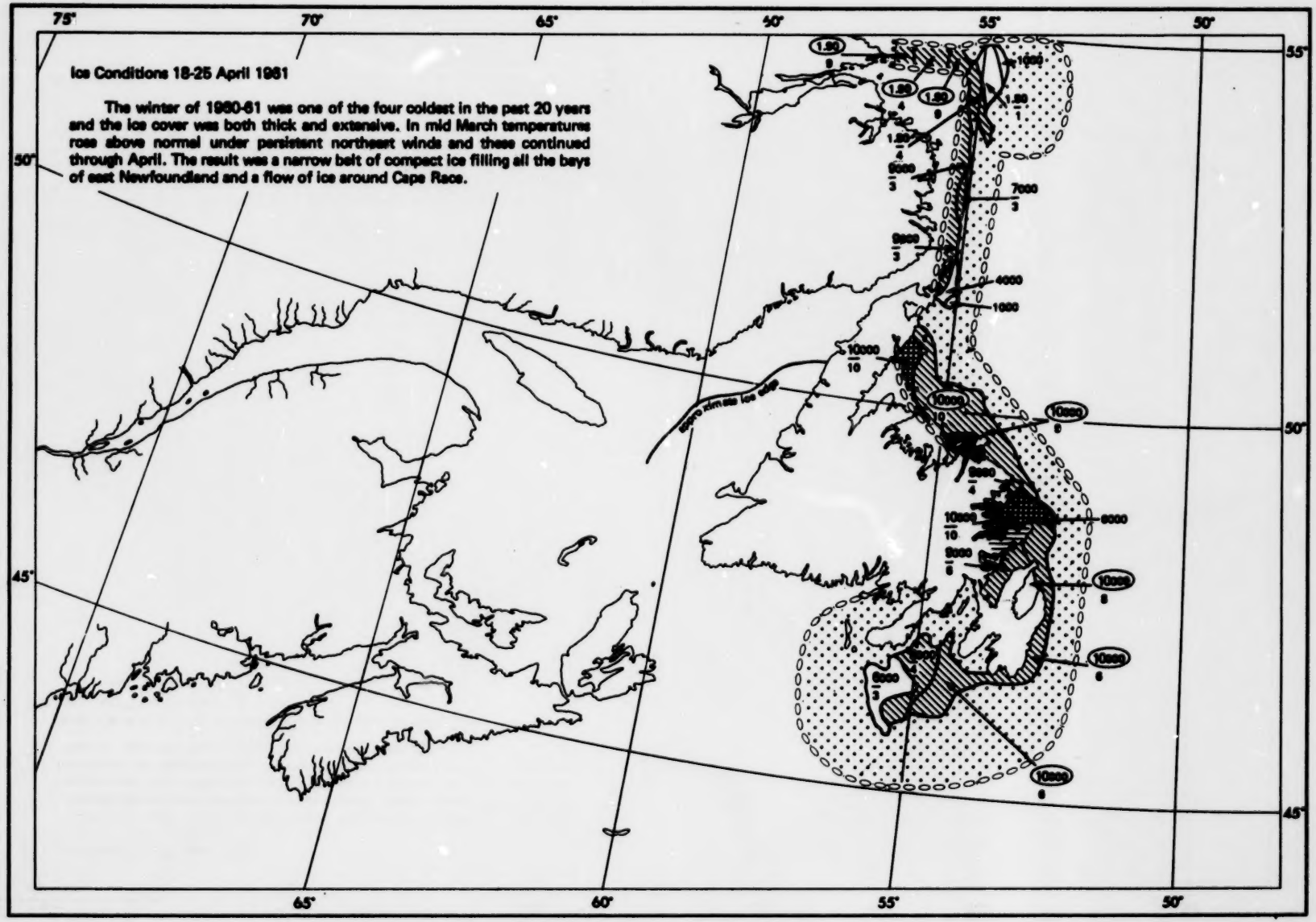
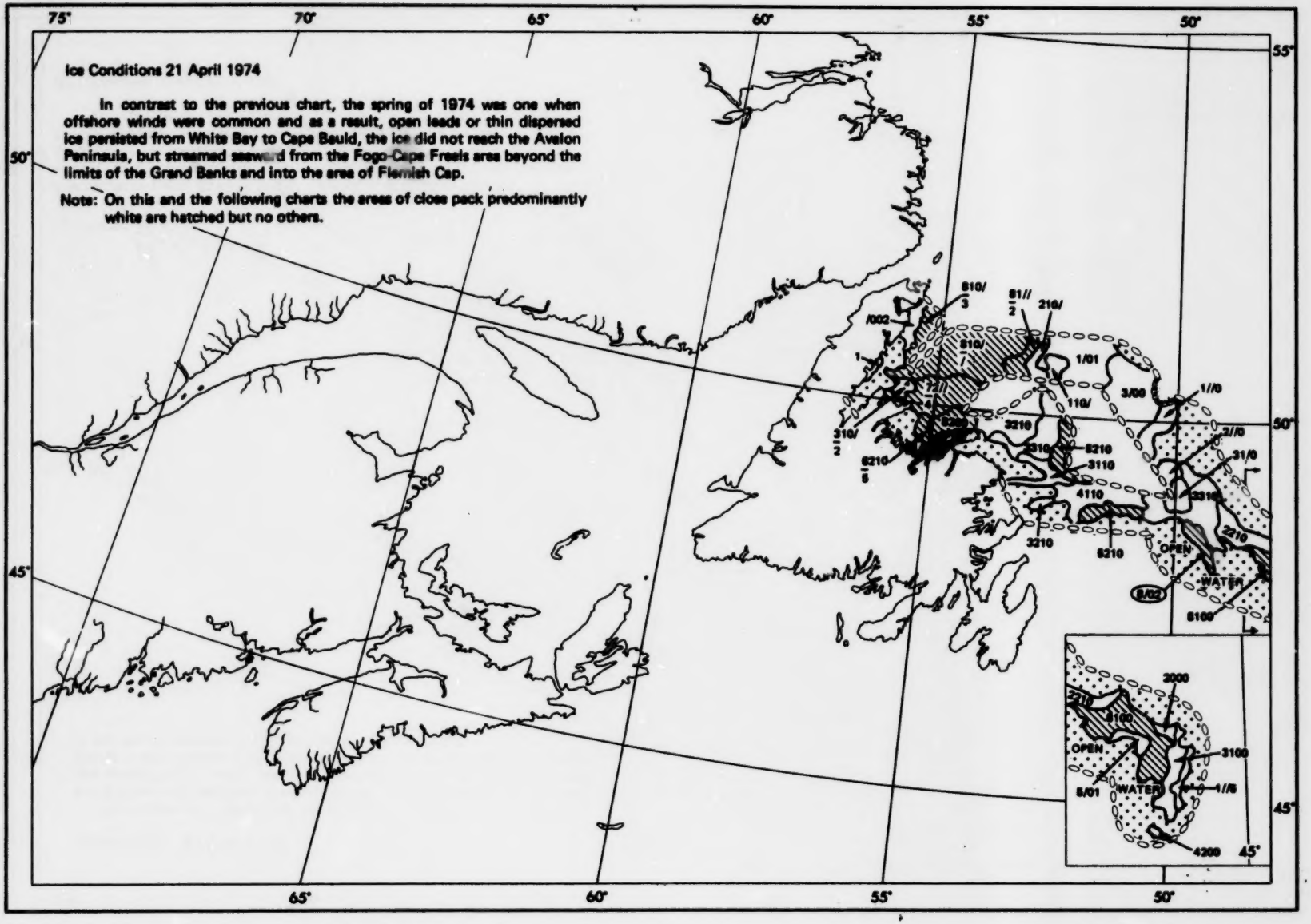


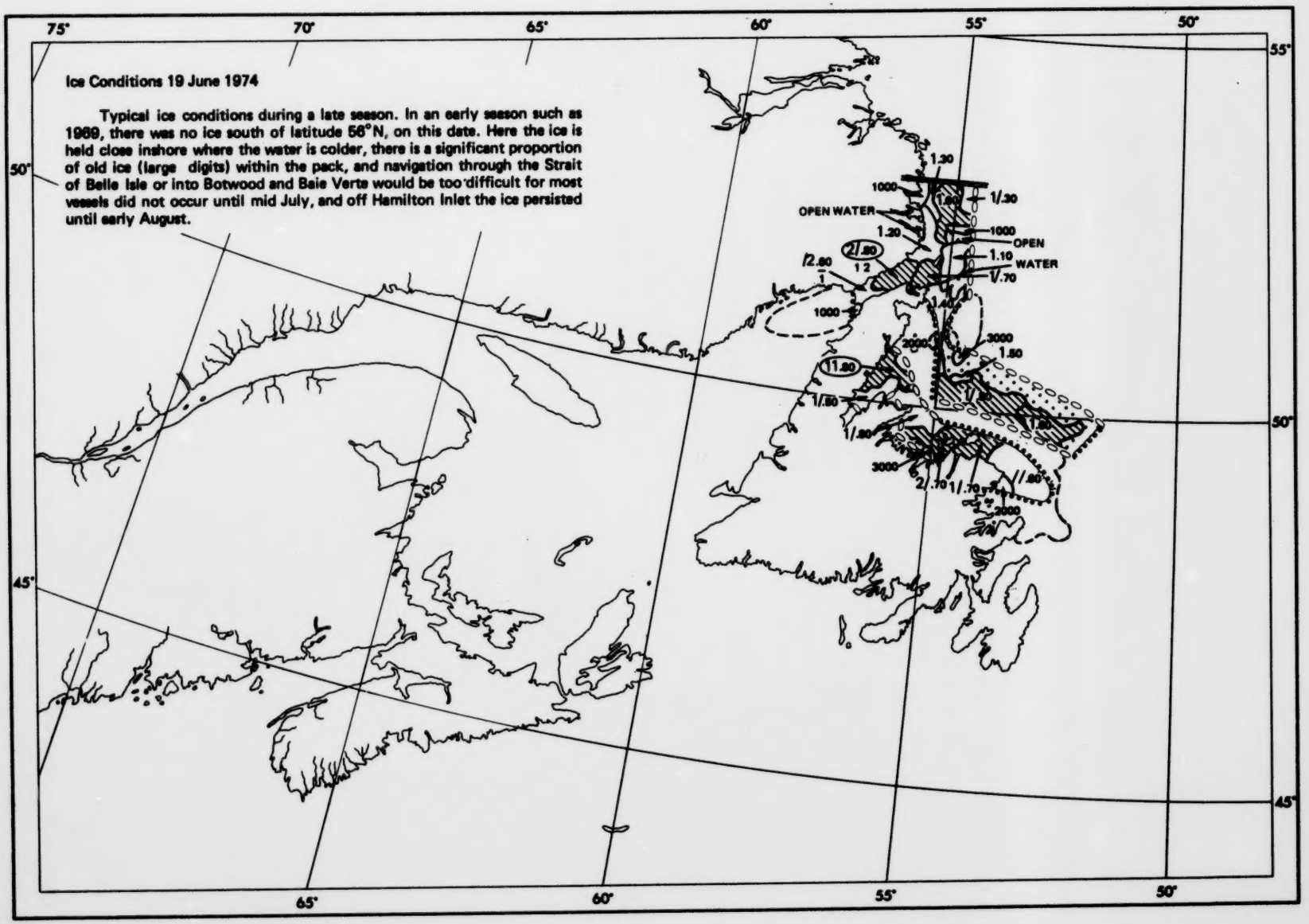
Ice Conditions 16-17 March 1969

After the mildest winter since 1958 this was the ice situation in mid March, a time when median conditions are close pack ice over most of the Gulf with dispersal under way in the Baie Comeau – Sept Isles area. Cabot Strait and its southern approaches are usually ice covered as well. The dearth of ice is also apparent in the Belle Isle – Spotted Island area.


Ice Conditions 15-16 March 1972
After the coldest winter in over 10 years the Gulf was congested with ice in mid March. Its extent is not greatly different from the median but its thickness – the proportion of white ice within the pack is far greater than normal. At this time navigation was extremely difficult all the way from the approaches to Cabot Strait to within a few miles of Anticosti Island.
OPEN WATER
75°
70°
65°
60°
55°
50°
55°
50°
45°
65°
60°
55°
50°


Ice Conditions 18-25 April 1961
The winter of 1960-61 was one of the four coldest in the past 20 years and the ice cover was both thick and extensive. In mid March temperatures rose above normal under persistent northeast winds and these continued through April. The result was a narrow belt of compact ice filling all the bays of east Newfoundland and a flow of ice around Cape Race.
75°
70°
65°
60°
55°
50°
45°


75°
70°
65°
60°
55°
50°
55°
50°
45°
Ice Conditions 21 April 1974
In contrast to the previous chart, the spring of 1974 was one when offshore winds were common and as a result, open leads or thin dispersed ice persisted from White Bay to Cape Bauld, the ice did not reach the Avalon Peninsula, but streamed seaward from the Fogo-Cape Freels area beyond the limits of the Grand Banks and into the area of Flemish Cap.
Note: On this and the following charts the areas of close pack predominantly white are hatched but no others.
OPEN WATER
OPEN WATER
4200


Ice Conditions 19 June 1974
Typical ice conditions during a late season. In an early season such as 1969, there was no ice south of latitude 56°N, on this date. Here the ice is held close inshore where the water is colder, there is a significant proportion of old ice (large digits) within the pack, and navigation through the Strait of Belle Isle or into Botwood and Baie Verte would be too difficult for most vessels did not occur until mid July, and off Hamilton Inlet the ice persisted until early August.
75°
70°
65°
60°
55°
50°
55°
50°
45°
OPEN WATER
OPEN
WATER
1000
2000
3000

Chapter 2

ICEBERGS

The most picturesque, most dangerous and most publicized aspect of ice in the sea is the occurrence of icebergs. They differ from sea ice in many ways, probably the most significant one as far as mariners are concerned is that they are an intense local hazard to navigation rather than the limited but wide-spread problem offered by sea ice. Icebergs originate on land rather than from frozen sea water, and are deep-drafted with appreciable heights above sea level rather than being nearly level with a small draft.

The glaciers of west Greenland are the source of nearly all the icebergs found on the Eastern Canadian Seaboard but a few originate from our Arctic Archipelago, and on rare occasions a berg from east Greenland may reach Canadian waters. Most of the active glaciers in east Greenland are located between Cape Farewell and Scoresby Sound (Latitude 61 - 70°N), for the more northern ones are situated in lengthy fiords having shallow still depths and moreover, sea ice blocks the outer coastline nearly all year round. Little is known of the production rates although Smith (1928) estimated it as 7,500 bergs per year at a time when production in west Greenland was also estimated to be 7,500.

From Canadian glaciers, berg production was estimated to be 150 per year by Smith (1928) and this figure still seems reasonable. There are less than ten active tidewater glaciers on Baffin, Bylot and Coburg Islands, a dozen or more on Devon Island and about 60, of which 24 are "sizable" on southern and eastern Ellesmere Island. Some bergs are calved in the Nansen Sound – Greely Fiord – Eureka Sound waterway but their numbers are small and access to Baffin Bay and the North Atlantic Ocean is difficult.

Glaciers in west Greenland are very numerous but the productive ones are concentrated between Smith Sound and Disko Bay. To the north, the glaciers of Nares Strait are relatively slow moving, they are blocked by sea ice a large proportion of the time and even though the huge Humboldt Glacier is in this area, yearly production is only estimated in the range from 100-200 bergs. More than double this number are calved from the 25 active tidewater glaciers between Smith Sound and Cape York. Melville Bay – from Cape York to Upernavik – is thought to be the major source of icebergs that affect Canadian waters; a production of over 10,000 bergs per year from 19 major glaciers is estimated. Nine of these are more than 8 kilometres wide across their fronts and one, the Steenstrup Glacier, is 26 kilometres wide and very productive. Northeast Bay (Karrats and Umanak Fiords) is also important for 10 major glaciers produce 5-8,000 bergs annually. Finally Disko Bay, with two major glaciers, produces a similar number.

To the south of Disko Bay, although the heads of most fiords are filled with ice tongues, the valleys are longer, narrower, and shallower than in the more northern areas and any calving is in the form of growlers rather than icebergs and these nearly always melt before reaching the open sea.

Total production of icebergs from Baffin Bay is therefore in the range of from 25-30,000 but estimates vary up to as high as 40,000. The first estimate, produced by E. H. Smith after the Marion Expedition was 7,500 bergs per year. In 1948, the US Coast Guard who operate the International Ice Patrol did an aerial reconnaissance of the entire Baffin Bay north of Cape Dyer and found over 12,000 bergs by visual count. The survey was repeated in 1949 but in addition, aerial photographs were taken to provide a more accurate census figure. The results were rather surprising – 17,500 bergs by visual count and over 40,000 from the photographic analysis (**Figure 4**). On this basis the adjusted census for 1948 would be close to 27,000 bergs. These numbers certainly indicate that production is several times greater than Smith had estimated but since we do not know the average residence time in Baffin Bay between the date a berg emerges from the fiord and the date it either melts or passes Cape Dyer, the actual production figure remains rather vaguely in the range between 20,000 and 40,000 per year.

DRIFT OF BERGS

The water currents of Baffin Bay are relatively simple for there is a warm, north-moving flow on the Greenland coast and a cold south-flowing current on the Baffin shore which continues down the Labrador coast and onto the Grand Banks. The west Greenland current often reaches speeds of one knot after rounding Cape Farewell but it diminishes in volume and speed as it progresses northward because of

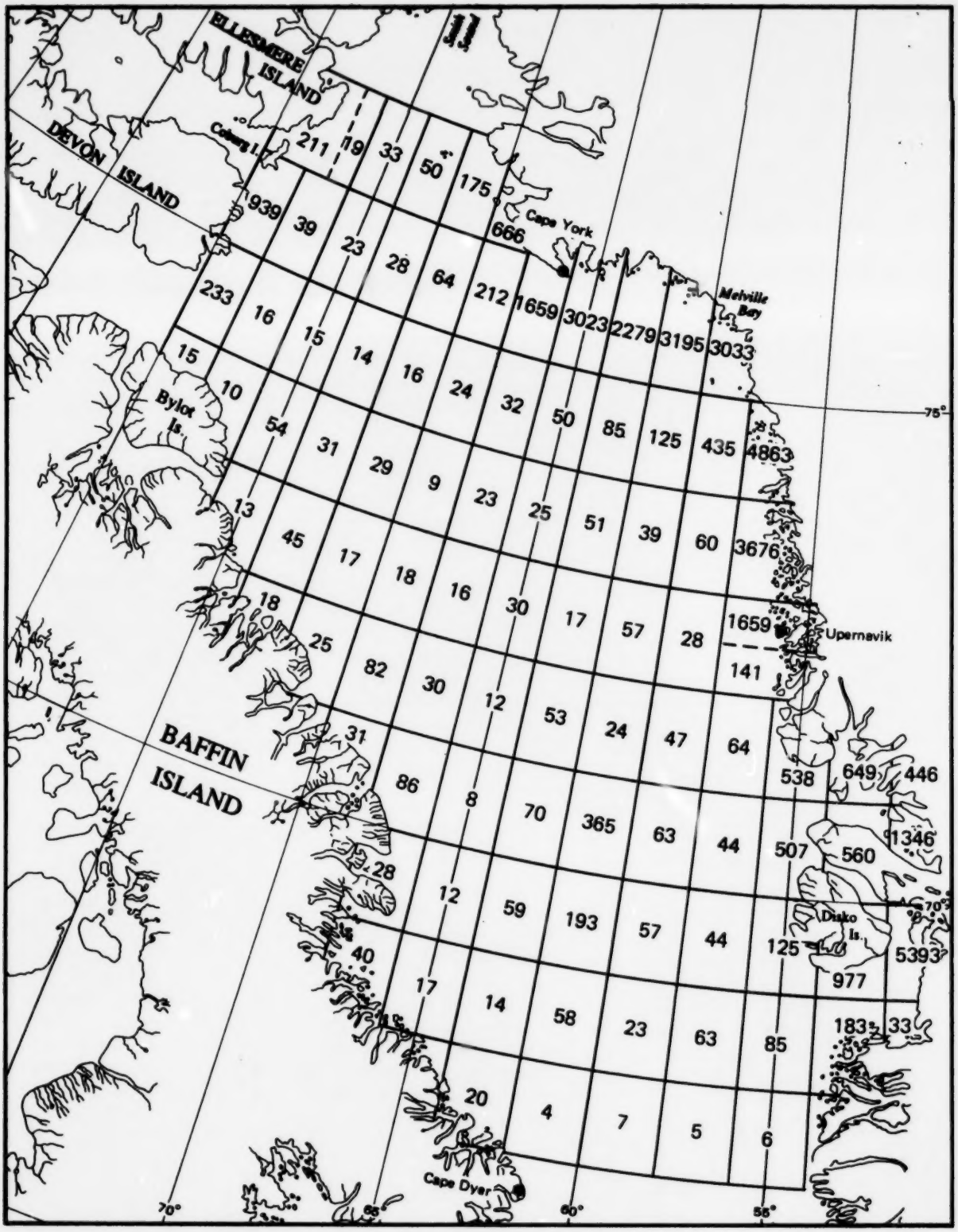


Figure 4 – Iceberg census of Baffin Bay 10-18 August, 1949 reported by International Ice Patrol (U.S. Coast Guard) after photographic analysis.

eddies branching westward. In Davis Strait and also near latitude 70°N, major westward branches are found and these may have a significant impact on the berg population and residence times. Although it is normal for bergs from Disko Bay to be carried northward to Melville Bay and Cape York before heading southward, it is also possible that some can emerge to the south of Disko Island, to be diverted into one of the west-branching eddies and, assisted by timely winds, reach the south-flowing Baffin Coast current without passing north of latitude 71°. This is not the normal behaviour but trains of bergs have been detected in the middle of southern Baffin Bay apparently undergoing this "short circuit". The latitude of these eddies is rather changeable and relates to variations in both wind and current.

According to tradition, sea ice moves in response to the wind and icebergs move in response to the current. Stories abound of bergs moving upwind against the sea ice. In actual fact, the situation is somewhat different and although extremes are still possible, the more usual situation is as follows:

An ice floe is large in horizontal extent in comparison to its draft and is therefore affected by surface currents only. Anything floating in the sea is carried along by current and sea ice is no exception. One can consider the sea ice as moving in response to the wind drag while being carried in a somewhat different direction by the water current. The net motion is the vector sum of the two forces. Because the wind effect is roughly 2% of its speed, a drift of 10 nautical miles per day in response to a 20 knot wind is not unusual, whereas a 10 nautical mile per day current is in the upper range of normal conditions. Combinations of these two relatively similar speeds can produce very variable results in the net drift direction.

Icebergs are also carried along by the current but in this case it is an integrated average of the water motion over the whole draft of the berg. Resultant speeds in this situation are much less for the idealized Ekman currents are very much diminished and deflected to the right as depths increase. Nevertheless, a berg motion due to current can be in the range of 10 nautical miles per day along the Labrador Shelf. Bergs are also exposed to the wind and although they protrude higher out of the water, their total cross sectional area is much smaller in comparison to their mass than in the case of sea ice. As a result, the vector force exerted by the wind is smaller and the bergs seem to respond only to current. In high wind situations however, this is not the case and the effect of the wind becomes significant, particularly if the sea is free of sea ice and a wind-generated current can develop. Small disintegrating bergs with shallow drafts are more easily influenced by wind and wind-induced currents than the large massive ones with deep drafts.

The main point about wind and current drift is that although both affect sea ice and icebergs, the relative importance of the two vector forces changes with exposed area and mass of the ice and with the strength of both wind and current. One of the early drilling vessels on the Labrador coast was "chased" from the drilling site by a berg which first passed abeam the drill ship but then was carried back northward by a gale and did not miss on its second "attempt".

The general life cycle of an iceberg is as follows: During the summer or fall after calving, it is carried seaward from the fiord and begins its counter-clockwise drift around Baffin Bay. Rates of motion along the Greenland coast are 3-5 nautical miles per day so total drift before freeze-up will vary from 200 up to about 600 nautical miles. Survival rates during this open water season are low – only about one berg in five lasts long enough to pass beyond Cape York. Considering water temperatures and drift rates it becomes apparent that most of these survivors will come from the sector between Cape York and Upernavik and that, in general, only the large Disko-area bergs reach Canadian waters unless they are diverted directly across Baffin Bay.

During the first winter, some progress around the gyre will be made but the extent is not well known. Obviously there will be no melting either above or below the water line and no wave action to assist in heat transfer. It is known that the summer "crop" of bergs that will affect the Grand Banks are located south of Cape Dyer in January and February during normal seasons. To achieve this position, the bergs must be at least at the head of Baffin Bay in mid October and even then, favorable winds will be required to traverse the 600 nautical miles to Cape Dyer by mid January. These bergs are subsequently carried southward to the Grand Banks late in the iceberg season, for the early bergs will be located along the Labrador coast in mid winter. It is possible for a berg calved in the Melville Bay area to reach the Grand Banks in the following summer, but remaining in the principal currents for this full period without grounding or being diverted into major inlets like Frobisher Bay, Hudson Strait or Belle Isle Strait is the exception rather than the rule. The average drift life of a berg is therefore probably between two and three years if allowances are made for these delays, and it becomes apparent that medium sized bergs in the Baffin coast stream have a better chance of reaching the Grand Banks than the larger ones which are more subject to groundings.

DECAY OF BERGS

The natural destruction of icebergs is accomplished in two ways – by melting and by repeated calving into smaller fragments. Of these two, the latter is the most efficient for every break that occurs will result in a greater surface of ice on which melting can occur. Melting itself can be broken down into that taking place below the sea surface because of warm water temperature and that occurring in the atmosphere because of air temperature, radiation or rainfall.

Sea temperature varies from approximately -1.5°C in winter up to 5°C in Baffin Bay in August, to 5-10°C on the Labrador coast and as high as 10-15°C on the northern Grand Banks. It must be remembered however, that sea temperature also varies with depth, and it would not be unusual for a moderate berg to be subject to melting in the upper layers of the sea but, because of its draft, to penetrate well into the sub-zero temperatures at greater depths. Icebergs are "fresh" ice and temperatures greater than 0°C are required for melting.

Air temperature and radiation go hand in hand for both are atmospheric factors. The rate of heat exchange between the ice and warmer air is low in comparison to that occurring below the waterline where solid and liquid are in contact. Radiation, on the other hand, is significant for the short-wave solar input penetrates into the berg raising the temperature and causing thermal stresses which ultimately contribute to calving.

Wave and swell action on a berg is also a very important decay mechanism for the continuing water motion is a very efficient way to dissipate the cooling effect of a berg and keep a supply of warmer water at the ice-water interface. The back and forth water motion expands cracks and depressions and, because the berg is afloat, the area of continued melt is in the central section. Erosion and calving at the ends of a berg cause a change in the equilibrium water line that lifts the newly-formed faces out of the water. Erosion in the centre merely increases the area exposed to the water action without changing the centre of gravity, and actually accelerates the decay even further. The "dry-dock" berg is one of the later stages of this process.

International Ice Patrol has studied the decay of bergs for many years and have developed the following:

DETERIORATION TIME (IN DAYS) FOR ICEBERGS

Surface Sea Water Temperature	Small Berg Under 15 m high Under 45 m long	Medium Berg 15-30 m high 45-90 m long	Large Berg Over 30 m high Over 90 m long
0°C	15	40	90
2.2°	8	16	24
4.4°	5	10	15

For tabular bergs the height limits are 6 m, 6-15 m and over 15 m.

General Remarks concerning the drift of bergs in Canadian waters

1. Part of the south-flowing cold current from Nares Strait and northern Baffin Bay enters Lancaster Sound and penetrates as a loop about as far west as longitude 85°W. As a result, icebergs occur in decreasing frequency as one progresses westward through the Sound. Also icebergs pass down Navy Board Inlet and eastward through Pond Inlet.
2. The same looping of the current into Hudson Strait carries bergs as far west as Big Island but some also penetrate Frobisher Bay, probably because of strong tidal streams into it.
3. Maps showing iceberg occurrences in Labrador and in Newfoundland waters follow as Figures 5 - 8.
4. A few icebergs penetrate the Strait of Belle Isle and (if the dominant flow is inward) may reach the Gulf of St. Lawrence. These are all small bergs however, for the limiting depth in the strait is about 55 m. Inflow on the north shore is most frequent, and outflow on the Newfoundland shore.

5. Most bergs that do enter the Gulf go aground along the Quebec shore east of Harrington Harbour but a few can penetrate to the Heath Point (Anticosti Is.) or Bay of Islands area. One small berg in 1960 reached Cabot Strait before melting. Such extreme penetrations usually occur in seasons when the sea ice is at a minimum and little resistance is offered to berg motion.

6. The long-term average number of bergs crossing latitude 48°N as determined by the International Ice Patrol is:

1945-1972	259	Maximum 1587 in 1972, 1386 in 1974
		Minimum 0 in 1966

64% of the bergs enter the area in April and May and 93% in the period March 1 to June 30.

7. Calculations of decay and drift rates indicate that the average number passing Belle Isle is 3.25 times greater than the number crossing latitude 48°N. The number passing Hamilton Inlet is nearly 6 times higher and in a normal season 8 times as many bergs pass Cape Chidley as reach the Grand Banks.

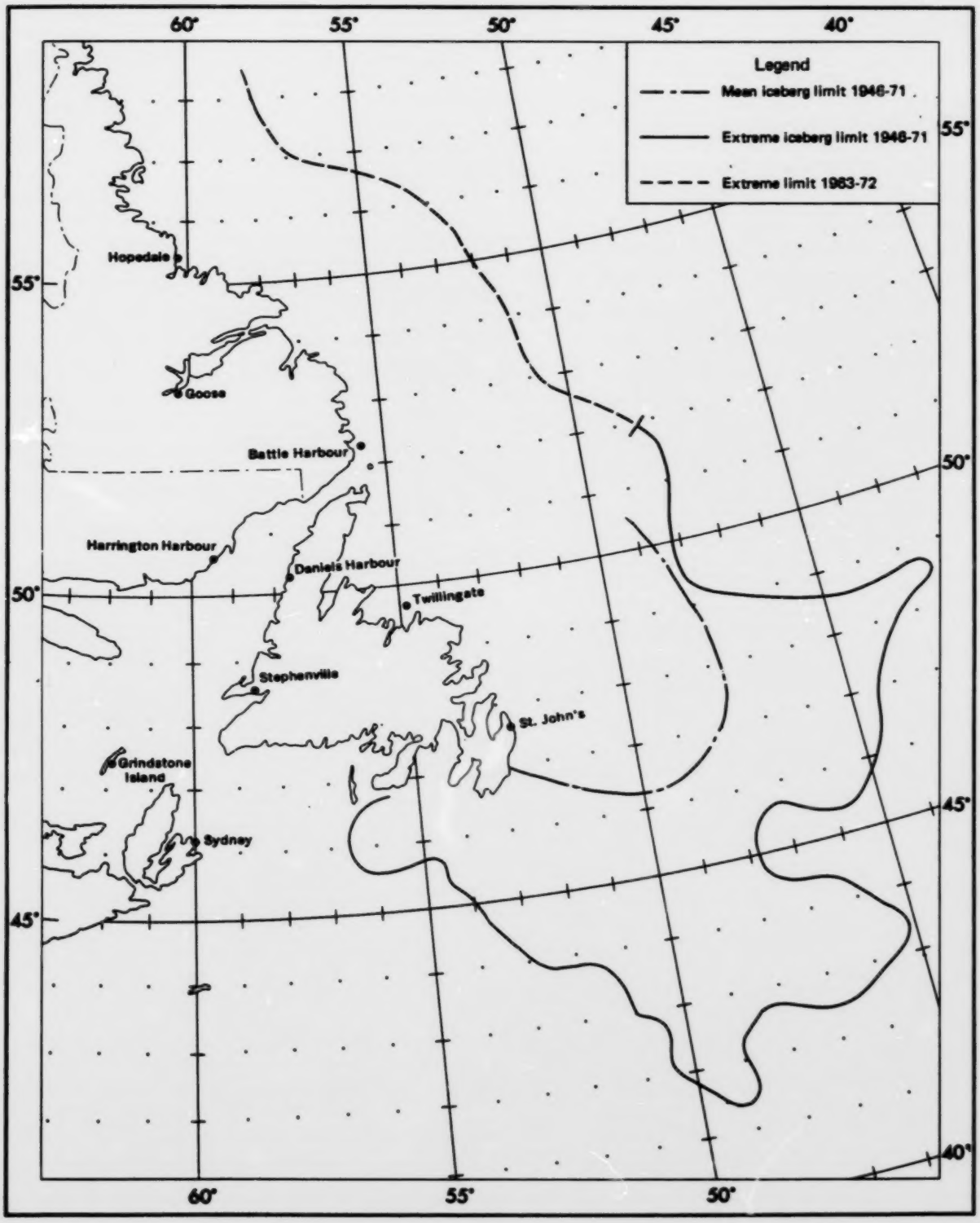


Figure 5 – March – Monthly iceberg limits (from International Ice Patrol data).

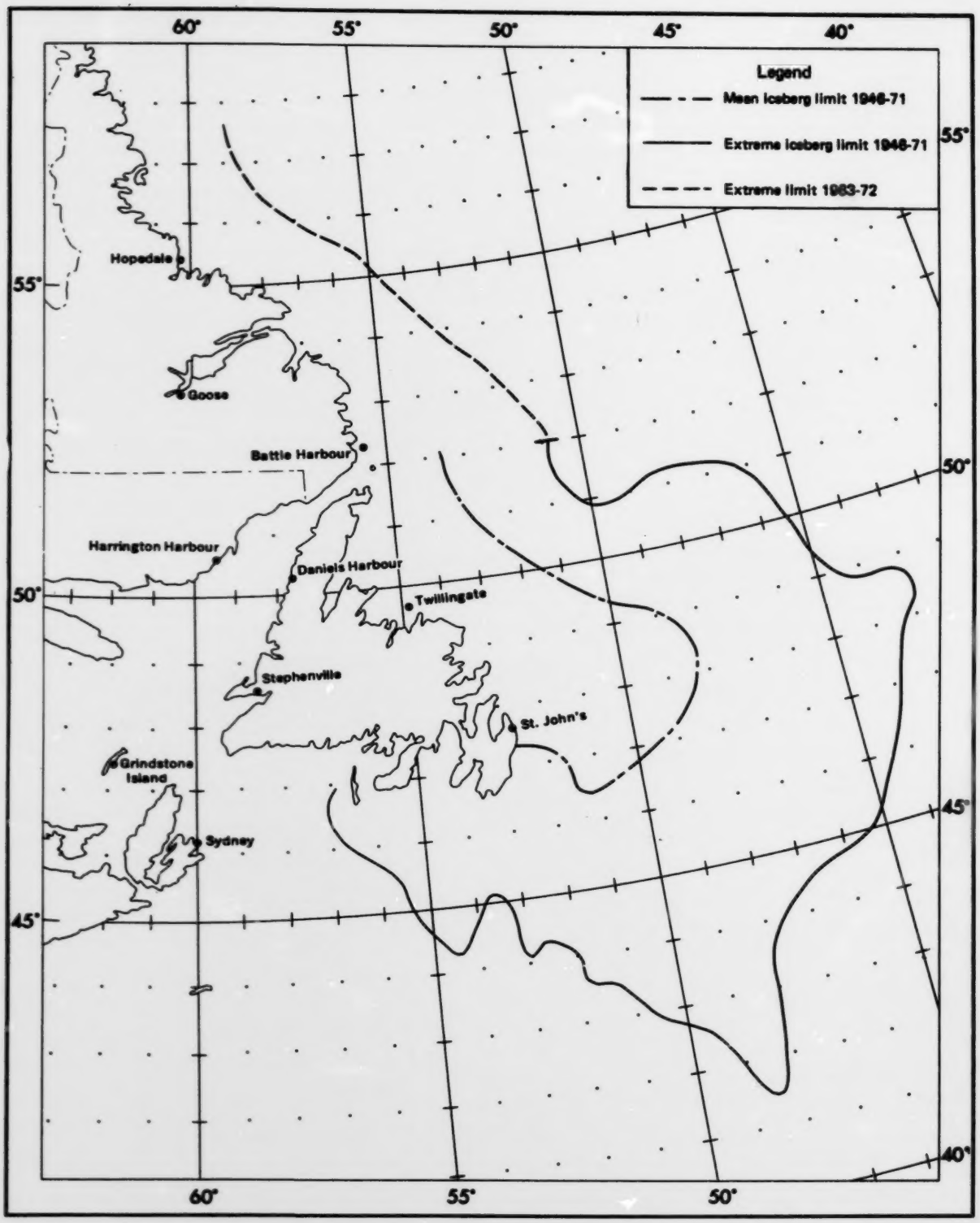


Figure 6 – April – Monthly iceberg limits (from International Ice Patrol data).

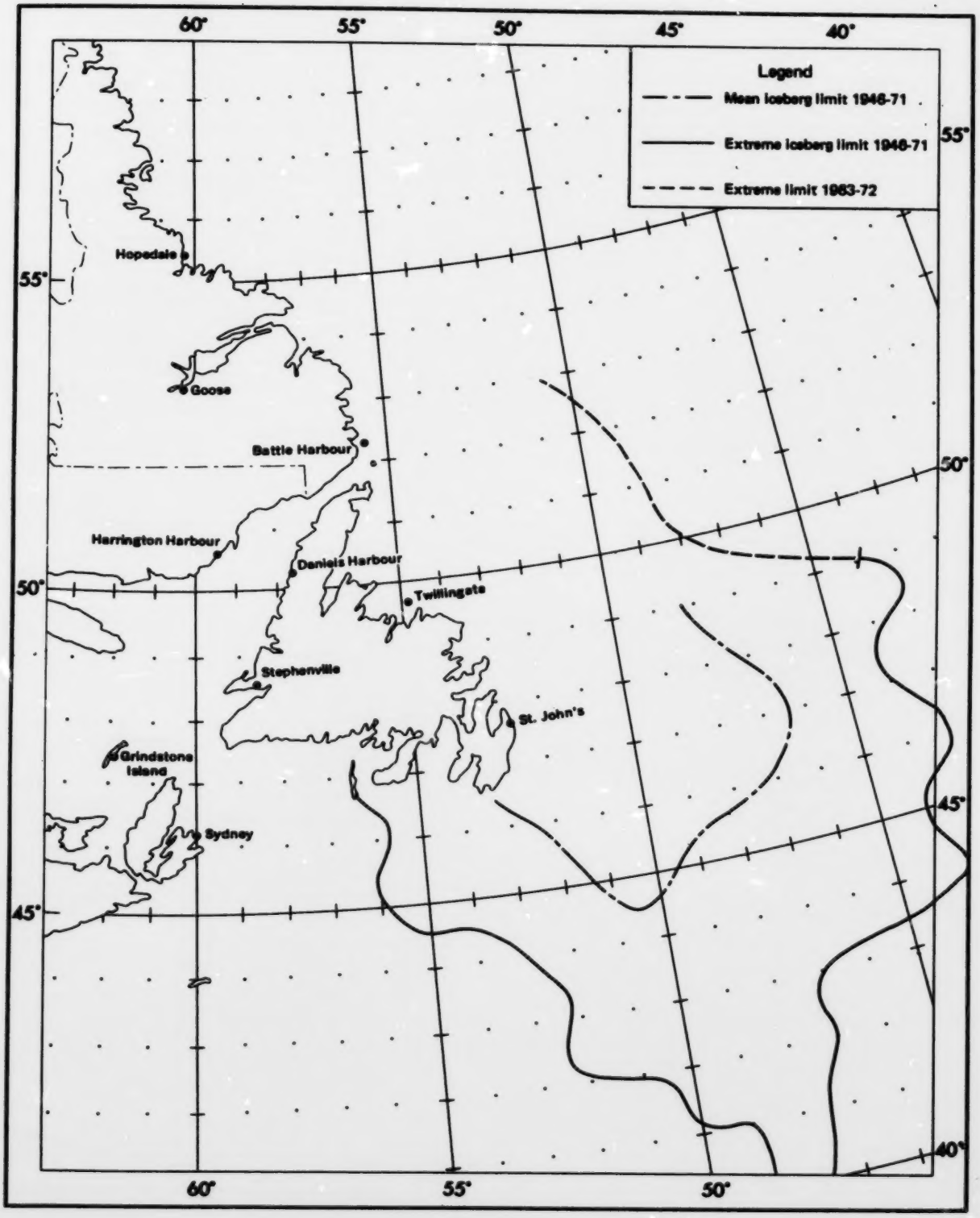


Figure 7 – May – Monthly iceberg limits (from International Ice Patrol data).

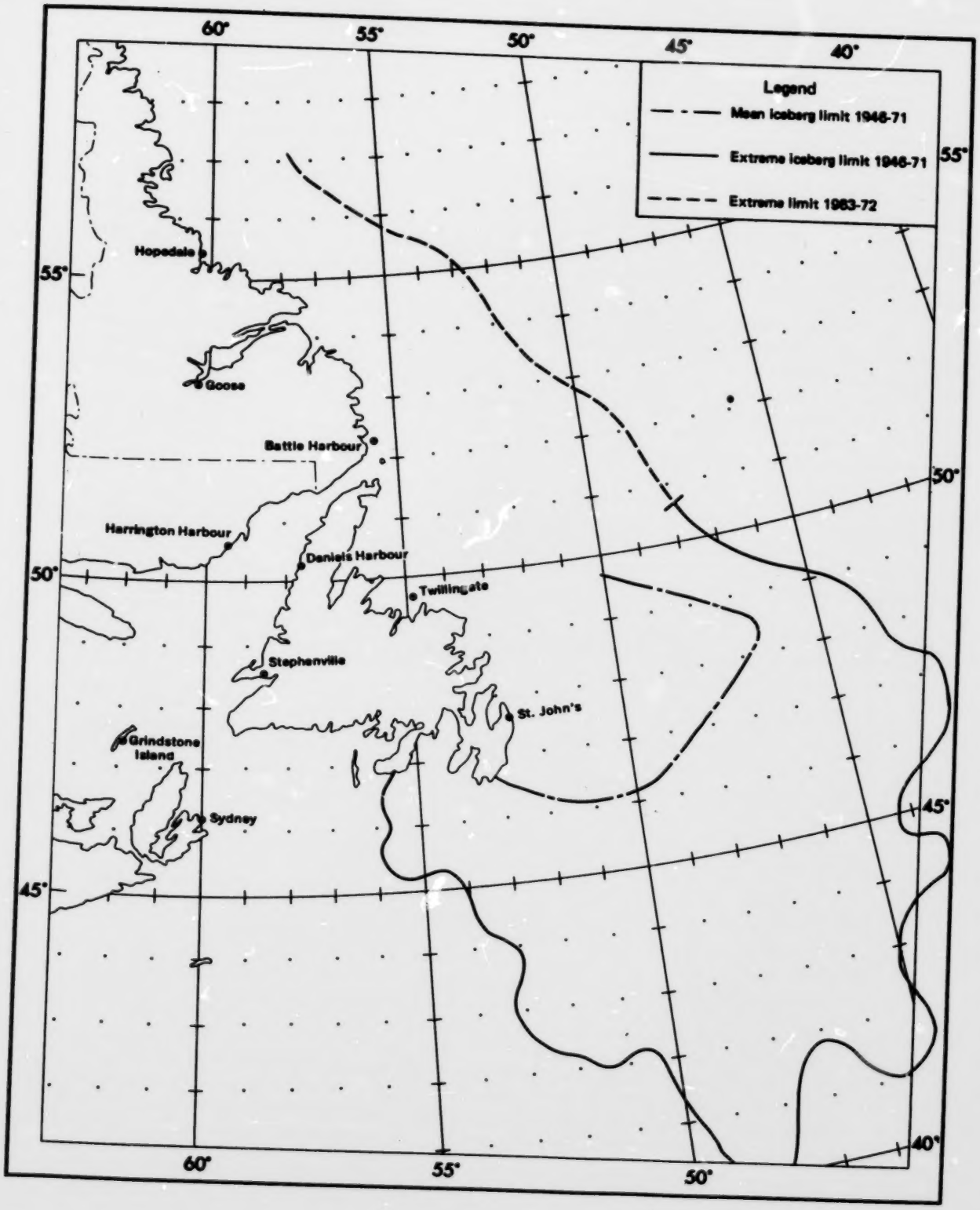


Figure 8 – June – Monthly iceberg limits (from International Ice Patrol data).

Chapter 3

OCEANOGRAPHY

Sea ice is an interface phenomenon occurring at the surface of the sea where it is affected by both the atmosphere and the underlying water. An understanding of the behaviour of sea ice requires a knowledge of both meteorology and oceanography because varying conditions above and below the surface affect its formation, movement, development, deformation and decay. The meteorological factors affecting sea ice and navigation through it are discussed in the following chapter. In this chapter the sub-surface conditions are examined.

The Gulf of St. Lawrence has an area of about 195,000 sq km (75,000 sq mi) and receives drainage through its rivers from an area seven times greater or 1,375,000 sq km (500,000 sq mi), reaching all the way to the head of the Great Lakes. The St. Lawrence is, of course, the major river flowing into the area but the volume and depth of the Saguenay River also have an effect on the ice regime.

The coastal section of east Newfoundland and Labrador covers 1,350 km (850 mi) of latitude (47° to 61°N) but has only one major river system – the Churchill, emptying into Hamilton Inlet through Lake Melville. The Strait of Belle Isle with a threshold depth of 55 m (180 ft) connects the eastern coasts to the Gulf of St. Lawrence.

The bathymetry of the areas are reasonably well known as are the major features of each section. The Gulf of St. Lawrence has a deep trench running from Cabot Strait to the Saguenay River with depths of 500 m decreasing to 200 m above Rivière du Loup. The southwestern part of the Gulf averages less than 75 m depth but there is a relatively deep channel between Anticosti Island and Newfoundland where depths are in the 250 m range. Even Jacques Cartier Passage to the north has a threshold depth of about 100 m.

The Grand Banks to the east-southeast of Newfoundland are very well-known and have average depths of about 75 m. To the northeast between Fogo Island and the Strait of Belle Isle, depths are somewhat greater averaging over 300 m but there are a few small banks with depths less than 200 m.

The bathymetry of the Labrador coast has been the latest to become known and is perhaps the most unusual. Along the general coastline, 50-100 km from shore (30-60 mi) there is a "marginal trough" with depths ranging from 200-800 m. Further offshore there are a series of broad banks with least depths in the 100-200 m range. The continental shelf extends 150-175 km (100 mi) from shore, is narrowest in the Hopedale-Hebron sector, somewhat broader to the north and much wider from Spotted Island (latitude 52° 30'N) southward.

CIRCULATION

The general water motion over these areas is relatively simple but the details are complicated and only partially known. A cold current flows southward through western Davis Strait, it follows the general Baffin shoreline (because the Coriolis force diverts it to the right) and continues southward along the Labrador coast after a portion of the transport is diverted in a loop into and out of Hudson Strait. On the Labrador coast the southward motion is mainly confined to the continental shelf and the water is coldest and least saline in the upper layers near shore.

After passing Hamilton Inlet, just as the continental shelf widens so does the breadth of the current. As a result, it decelerates, floods over the Grand Banks, and portions of the current continue southwestward from Cape Race towards Nova Scotia and Cape Cod. Along the northern Labrador coast, rates of motion are in the range of 10-12 nautical miles per day but these speeds are not usually constant from one season to the next or one year to the next. One recent summer study of iceberg motion north of Hopedale found drifts of 10 nautical miles per day, and non-progressive meandering in the same location and at the same time in the following year.

In the Belle Isle-Newfoundland area, surface currents are usually half or less of those on the Labrador coast, and the drift westward from Cape Race to Nova Scotia waters is even slower.

In the Gulf of St. Lawrence there are elements of counter-clockwise water motion but the pattern is far from complete and is affected by numerous other considerations. There is a net inflow of water around Cape Ray and a northward-flowing current has been observed along the west coast of

Newfoundland past Bay of Islands and Daniels Harbour. The northern limit of this drift and what happens to the water is as yet undetermined.

Through the Strait of Belle Isle there is a variable tidal stream which runs progressively outward in west wind situations and progressively inward when winds are easterly. At depth there is probably a net inward flow but at the surface the situation is variable. No significant quantity of ice enters the Gulf of St. Lawrence through this channel in winter.

Along the North Shore of the Gulf and through Jacques Cartier Passage no persistent currents have been found, rather a back and forth tidal swash is noted in the Mingan area. Near Heath Point, Anticosti Island, there is sometimes evidence of a current rounding the point and continuing along the south coast of the island but this, too, seems to be a non-persistent feature.

As one would expect, in the estuary of the St. Lawrence River, there is a net eastward current but superimposed on it are tidal streams which alternately accelerate and decelerate the motion. A cross-channel flow has been found in the Pointe des Monts to Cape Chat area and from here the "Gaspe Current" flows seaward. It runs at speeds up to 2.5 knots when westerly winds and ebb tides combine and is not known to have been reversed even with east winds and flood tide situations. The current is strongest at 2-12 nautical miles offshore and has a net volume almost 20 times that of the St. Lawrence River. Its source is not well identified but it is apparent that some vertical water motion is involved.

Once into the main portion of the Gulf, the water spreads over the Magdalen Shallows and drifts generally towards Cabot Strait but some portions also follow the deep Laurentian Channel directly across the Gulf. After reaching the vicinity of Cape Breton Island, the current pours around Cape North, sweeps through Sydney Bight, and dissipates on the Scotian Shelf off Scatari Island. Rates of motion in this stream may exceed 2 knots near Cape North and St. Paul's Island but over the Magdalen Shallows speeds of 3-5 nautical miles per day are normally found.

TIDES

The tidal ranges on the Labrador and Newfoundland coasts are fairly small but consistent, for, at most locations the mean range is from 0.6 to 1.5 m. In the Gulf of St. Lawrence the situation is somewhat more complicated because the tidal surge enters from both Cabot Strait and the Strait of Belle Isle. As an oceanographer would expect, one amphidromic point (where the tidal oscillations are at a minimum) is located in the western part of the Gulf but there are two other minor ones. The main centre is located just west of the Magdalen Islands, the others in Northumberland Strait and in the Strait of Belle Isle.

The main tidal surge progresses in a counter-clockwise manner around the Gulf after entering at Cabot Strait and mean ranges vary from 0.6 to 0.9 m at Cape North and Cape Ray to 1.2 to 1.4 m on the west coast of Newfoundland and 1.4 to 1.6 m along the north shore of the Gulf. In the estuary, ranges increase progressively towards the southwest from 2.5 m in the Pointe des Monts-Pointe au Père area to about 5 m near Quebec. In Chaleur Bay the tidal range is from 1.0 to 1.5 m but in the Magdalen Islands only 0.4 to 0.6 m.

Northumberland Strait has a complicated tidal pattern because of the amphidromic point and two entrances for the tidal surge. In the west end there is essentially one tide per day while in the eastern section there are the normal two with a range of 1.2 to 2.0 m. The Strait of Belle Isle has tides in the 0.5 to 0.8 m range.

The major effect on the ice regime of these tidal forces and tidal streams is related to the back and forth motion as the tides rise and fall. It is most apparent in the upper estuary but is also apparent in the Bay of Chaleur and its approaches. A low tidal range can also combine with shallow fore-shores to produce rather wide areas of fast ice.

WATER TEMPERATURE AND SALINITY

The temperature of sea water quite obviously varies from place to place and season to season. Less obvious though are changes in the salinity of the water in the open sea where run-off is not a factor. These variations depend primarily on precipitation and the amount of evaporation but also on vertical mixing as both temperature and salinity vary with depth as well as with location and time.

Sea water contains about 3% of dissolved salts making it somewhat heavier than the same volume of fresh water. The amount of the various salts in relation to each other is constant but the total can vary significantly. In the tropics where temperatures are high and evaporation is rapid, the salinity

may rise to 3½ or 4% but in other areas where precipitation is excessive or run-off is extensive, the salinity may fall below 1%. The Baltic Sea, the Gulf of Bothnia and Lake Melville fall into this latter category. Melting snow and ice also dilute the sea water.

Like most other materials water expands as it warms and the density therefore decreases. Dissolved salts in the water increase its density in proportion to the amount. Sea water has, thus, two factors which affect its density and in fact the three parameters – temperature, salinity and density are interrelated in a manner such that if any two are specified, the third is also defined. In this way, water and air are similar for temperature and humidity control air density. In the atmosphere there is also the factor of pressure which is a significant fourth variable. Pressure also affects water density but since a liquid is nearly incompressible this factor is much less important in the field of oceanography.

When a volume of sea water is cooled, its density increases and there is a tendency for it to sink below the surface to a level where the density of the surrounding water is equal to its own. In the process, mixing takes place and any variation with depth of temperature or salinity will be removed. Upon further cooling at the surface further mixing occurs, densities become somewhat higher and the depth of convective mixing increases. This process can continue until the water is cooled to its freezing point, since the density continues to increase as the temperature decreases and the vertical mixing proceeds to greater and greater depths. It is this process which delays the freeze-up of salt water areas compared to fresh water lakes, because in fresh water the maximum density is at 4°C and below this point there is a small expansion with additional cooling. A fresh water lake develops vertical mixing in the autumn as does sea water, until the mixed water temperature decreases to 4°C. Further surface cooling decreases the density and the heat loss is confined to surface layers rather than being spread through the mixed layer as in sea water.

The whole process of cooling, vertical mixing, and eventual ice formation in sea water is analagous to heating, vertical mixing and eventual cloud formation which goes on in the atmosphere on a fine summer day. The sun's heat warms the air, starts vertical convective currents that gradually rise higher and higher as the temperature increases, until the condensation level is reached and clouds form. Their height depends on the humidity of the air and the rate at which the temperature changes with height. In the ocean, cooling produces denser water that sinks as a vertical convective current. The depth of the convection gradually increases with further cooling until ice is formed. The depth of the mixing is controlled by the temperature and salinity change with depth.

In the Gulf of St. Lawrence there are three main "layers" of water, for during the summer, temperatures first decrease with depth, then stabilize at about 0°C and finally begin to rise. There is thus a warm layer in the deep channels with temperatures in the range of 2 - 5°C and salinities of about 3½%, sufficient to make this the heaviest layer despite the warm temperatures. Overlaying this deep layer, at depths of 50 to over 100 m is an intermediate cold layer with temperatures of 0°C or lower and salinities of 3 to 3.3%. The thickness of this layer is at a maximum in spring and a minimum in the fall because of varied mixing with the surface layer. In the surface layer, temperatures are dependent upon the season for in the winter, because of vertical mixing, isothermal conditions at -1.6°C are found with salinities of 2.6 to 3.2%. During the spring and summer, temperatures warm progressively to as high as 20°C at the surface but remain at 0° to 5°C at depths of 20 - 30 m.

The intermediate cold layer isolates the deep warm layer from the surface and is largely the result of winter cooling and vertical convective circulation. Some cold water from the Labrador current enters through the Strait of Belle Isle at depth but the volume of this inflow is itself, insufficient to maintain the cold layer throughout the Gulf during the summer warming. The presence of the layer does have an effect on the ice which increases its thickness over what would otherwise develop.

Waters of the Labrador current or those resulting from it, occupy the remainder of the Canadian coastal area. This is a simple cold flow with salinities in the 3 - 3.5% range. Temperatures in the surface layer vary from -1.6° to -1.0°C in winter in all areas to 10 - 15°C in Newfoundland waters in summer and 3 - 8°C along the Labrador coast. In the sub-surface layers temperatures remain less that 0°C year-round. In general the coldest and least saline water is near the surface and close to shore.

This cold current is confined to the continental shelf and beyond the slope, warmer and more saline water is present. This effectively confines the belt of ice moving down the Labrador coast to the same general area.

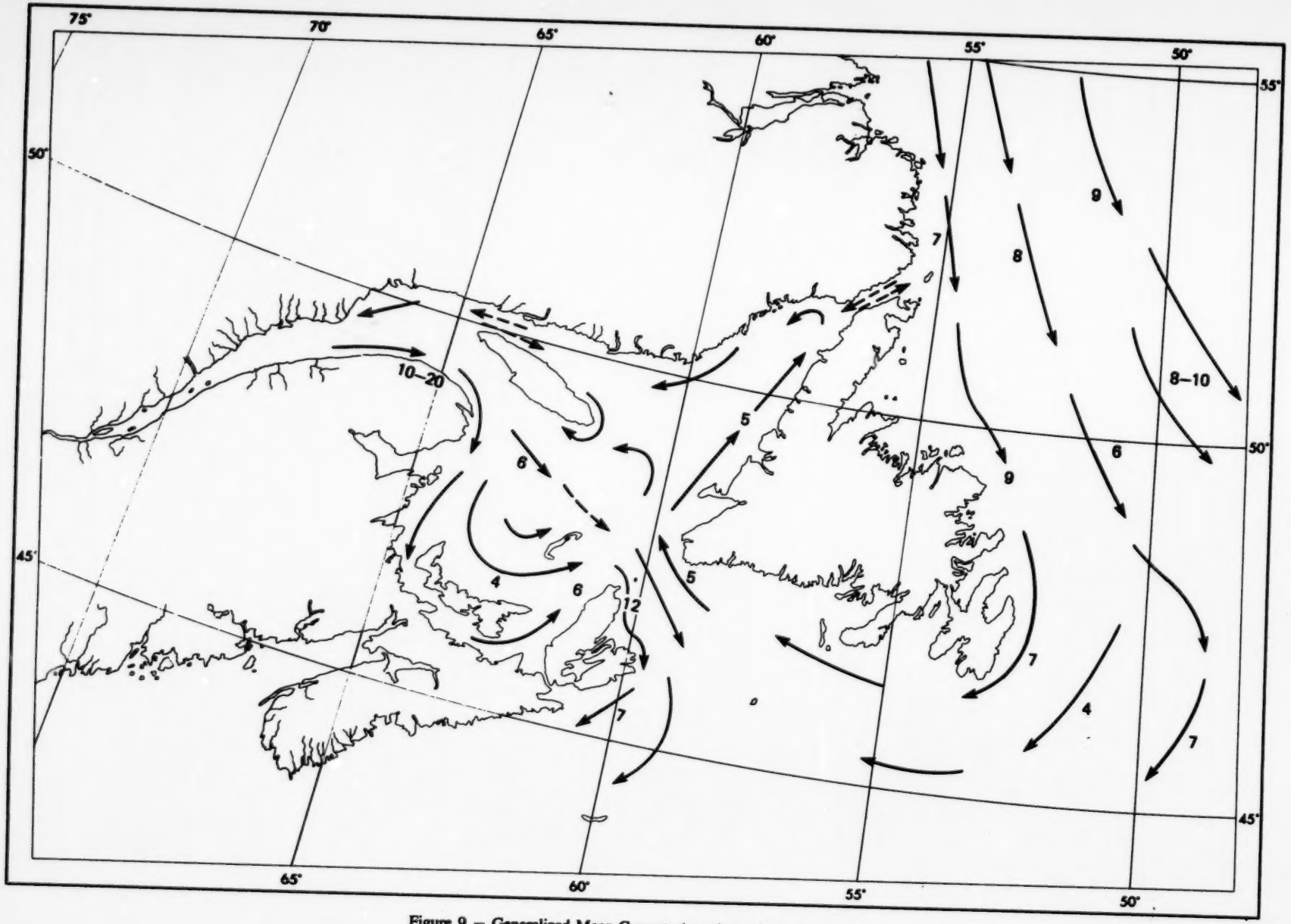


Figure 9 – Generalized Mean Currents (speed: nautical miles/day).

Chapter 4

METEOROLOGICAL CONDITIONS

Weather has a direct bearing on the planning and execution of winter navigation because temperatures control the extent and thickness of ice that forms, and the surface winds modify its location, form and distribution. During the planning stages and during design studies climatological data is needed, but during actual vessel transits through the ice, weather itself is of primary importance. On the following pages a selection of tables and charts are presented which are intended to convey this pertinent data in both these fields.

1. TEMPERATURE

Mean and extreme temperatures from a selection of coastal weather stations are plotted. Particular attention is directed towards conditions at Grindstone Island, St. John's, Twillingate and Battle Harbour for these most closely represent conditions at sea in the appropriate regions. The standard 30-year interval 1941 - 1970 is used wherever possible.

At a few locations, analysis of hourly temperatures during the 10-year period 1957 - 1966 has permitted substitution of the upper and lower 10 and 20% frequency lines for the mean maximum and minimum temperatures for these can be useful both in planning and in operations. Since hourly readings were used the lines are not directly related to the daily maximum, minimum and mean temperatures on the other graphs however.

2. PRECIPITATION

Rather than the conventional figures showing the amount of precipitation, the frequency of its occurrence is shown in a double table, days of measurable rain and days of measurable snow. If precipitation amounts are required, the data can be obtained readily from conventional meteorological sources.

TABLE 2 – DAYS OF MEASURABLE RAIN AND SNOW

N.B. Days of rain are shown first followed by days of snow in bold numerals.

	Nov.	Dec.	Jan.	Feb.	March	April	May	June
Quebec	10/8	4/15	2/15	1/14	4/10	9/4	12/*	
Mont-Joli	8/8	2/16	2/17	1/15	3/11	7/6	11/1	
Sept-Iles	6/8	2/12	1/15	1/12	2/10	5/6	10/1	
Fox River	9/7	3/16	1/16	2/11	3/12	4/6	11/2	
Campbellton	9/7	3/11	2/14	1/12	4/10	7/6	13/1	
Chatham	11/5	5/11	4/13	3/11	5/10	9/6	12/1	
Charlottetown	14/4	8/13	6/14	4/12	6/11	9/5	13/1	
Sydney	16/4	10/14	8/15	7/14	8/12	10/6	14/1	
Harrington Hbr.	10/7	5/14	4/15	3/14	3/13	6/9	12/3	
Stephenville	14/7	8/19	6/22	5/19	5/14	9/9	13/1	
Grindstone Is.	14/4	7/14	5/18	4/14	5/11	8/7	12/1	
St. Andrews	14/5	8/15	7/16	5/13	6/11	9/5	12/1	
St. John's	16/3	11/16	9/17	8/16	9/15	12/10	14/3	
Bonavista	14/3	9/10	6/12	7/11	7/10	8/8	11/3	
Twillingate	11/4	6/10	5/12	4/11	4/10	7/7	10/2	
St. Anthony	14/5	3/9	3/10	2/10	3/9	5/6	9/2	11/*
Battle Hbr.	9/7	1/7	2/8	*/8	1/8	4/5	5/3	8/*
Cartwright	6/10	3/13	3/15	2/13	2/15	4/12	11/7	14/1
Goose Bay	5/12	2/15	1/16	1/13	2/14	4/11	11/6	15/1

*average less than .5 day per month.

3. VISIBILITY

This element is very important to marine navigation and data is presented in two forms. In the first, Table 4, the occurrences of fog with visibility less than 1 km are averaged from synoptic weather reports. A day of fog is considered to have occurred whenever a visibility of less than 1 km is reported at one of the observation times. It does not imply that fog existed for the whole day or any specific portion of the day. Morning fogs in these reports have the same importance as a persistent and widespread "peasouper" even though the duration of the former may be only an hour or two.

To compensate for this imbalance as much as possible, the average hours of fog with visibility less than 1.6 km, and with visibility .8 km or less are shown for several locations. These reductions include those caused by snow and other phenomena besides fog and are thus of maximum significance between land and sea, for all of these data are derived from airport reports and do not fully represent conditions in nearby waterways.

Data has been abstracted from CDS #1-69 and Hourly Data Summaries for various airports (10 year periods).

TABLE 3 – NUMBER OF DAYS WITH FOG
(visibility less than 1 km at any time)

	Dec.	Jan.	Feb.	March	April	May	June	Yrs. of Data
Quebec	3.1	2.8	2.2	2.6	3.5	2.1		28
Pointe-au-Père	0.2	0.1	0	0.3	2.4	4.7		10
Sept-Iles	2.1	1.7	1.8	3.0	3.8	5.0		26
Natashquan	1.7	0.7	1.0	1.6	4.1	5.9		28
Southwest Pt.	1.1	2.1	1.8	3.0	6.4	10.4		9
Fox River	1.7	0.4	1.3	2.3	2.8	4.5		12
Campbellton	0	0	0.8	0.4	1.7	0.3		16
Chatham	2.8	2.5	2.0	2.4	4.3	2.8		28
Charlottetown	2.8	3.5	3.1	4.4	4.7	4.5		27
St. Paul Is.	2.9	3.6	4.2	4.8	9.1	11.9		16
Sydney	3.8	3.9	4.6	5.8	8.7	11.0		30
St. Andrews	0.5	1.1	0.4	1.4	3.3	3.9		22
Stephenville	4.8	3.5	4.6	4.7	8.4	10.1		19
Daniels Hbr.	0.9	0.8	0.2	0.9	2.0	3.7		23
Harrington Hbr.	2.2	1.7	2.4	2.5	5.0	6.9		25
Grindstone Is.	3.7	4.5	4.0	5.9	8.8	11.4		30
St. John's	7.0	7.6	7.9	9.4	13.0	15.7		29
Bonavista	4.2	3.7	5.3	8.6	11.0	13.4		10
Twillingate	1.2	2.5	2.3	4.5	5.1	6.5	7.4	16
St. Anthony	2.5	2.0	2.8	2.9	5.1	8.0	8.7	24
Belle Isle	6.9	5.9	5.1	8.1	11.5	16.2	18.3	29
Battle Hbr.	4.0	2.1	2.9	5.6	5.5	11.3	12.1	10
Cartwright	0.9	1.4	2.2	2.9	3.1	4.4	4.8	29
Goose Bay	1.1	0.7	0.8	1.0	0.8	1.3	1.1	29

TABLE 4 – MEAN HOURS OF REDUCED VISIBILITY PER MONTH AT COASTAL AIRPORTS

	Dec.	Jan.	Feb.	March	April	May	June
Quebec							
Vsby <0.8 km	23.5	10.6	11.3	13.6	13.6	3.1	
<1.6 km	69.7	45.5	43.5	43.2	42.0	22.9	
Mont-Joli							
Vsby <0.8 km	21.3	21.0	13.5	18.2	12.8	10.5	
<1.6 km	62.2	65.9	55.5	46.9	39.9	29.8	
Sept-Iles							
Vsby <0.8 km	16.4	15.1	15.7	17.7	10.8	15.3	
<1.6 km	51.4	55.0	53.0	51.6	33.8	59.6	
Chatham N.B.							
Vsby <0.8 km	24.1	20.1	17.4	21.9	17.2	8.7	
<1.6 km	71.2	62.9	58.5	72.8	59.8	46.4	
Charlottetown							
Vsby <0.8 km	23.3	24.5	21.3	36.0	22.8	20.2	
<1.6 km	77.3	77.4	67.2	92.7	76.9	71.7	
Sydney							
Vsby <0.8 km	20.1	22.6	26.5	36.6	25.3	38.1	
<1.6 km	85.8	91.3	86.2	126.2	108.2	129.6	
Grindstone Island							
Vsby <0.8 km							
<1.6 km							
St. John's							
Vsby <0.8 km	34.2	61.1	74.4	102.3	112.2	84.8	
<1.6 km	123.9	157.6	179.5	220.0	220.2	190.2	
Goose Bay							
Vsby <0.8 km	5.8	5.9	6.9	9.4	4.0	5.4	1.4
<1.6 km	26.1	33.9	23.2	38.0	22.0	26.0	13.3

4. WIND

As mentioned above, wind direction and strength have considerable effect on the ice cover, for its thickness, its location and the degree of obstruction to navigation it presents are all related to the winter wind regime. Along the North Shore from the Saguenay River to Sept Iles, west and northwest winds are common and consequently coastal leads develop frequently. The ice cover along this shore is usually thin and navigation for moderately powered ships is rarely obstructed, whereas thick and congested ice is common along the Gaspe Peninsula.

To document these wind conditions, monthly wind roses are presented giving the percent of time the wind blows from each direction and the average strength it maintains. An eight-point breakdown is used. For Quebec, Grindstone Island and St. John's a further separation is provided which focuses attention on wind speeds greater than 29 km/h. These are the situations when pressure within the ice pack can arise, when navigation may become difficult, and when the ice is most mobile in either the compressive or dispersing mode.

Once again the problem of coastal versus over-water wind conditions is encountered for the added friction on shore affects both the speed and direction of the wind. It is clear that wind speeds at Grindstone Island are substantially higher than any of the coastal stations around the Gulf. From a study of ship reports it is known that these conditions are more representative of averages over the water than the shore-based data. This factor is discussed further in the section analyzing winds in the central Gulf.

ANALYSIS OF WINTER WINDS IN CENTRAL GULF OF ST. LAWRENCE

A weather observing station has been located at Grindstone Island in the Magdalen Islands since 1933 and the following analysis is based on 40 years of record from that site. The anemometer, (10 m above ground) is located near the top of a 65 metre hill with good exposure in all directions. Because of the hill and the height above sea level, wind speeds are unusually high for a land station but, in fact, are in fairly good agreement with those reported from ships in the central portion of the Gulf. At Sable Island, a low sandbar some 145 kilometres off the Nova Scotia coast, where winds are effectively the same as over the open ocean the mean annual wind speed over 30 years was 14.0 kt while at Grindstone Island the speed was 17.1 kt over the same period. The Sable Island anemometer is 10 m above sea level and the height difference accounts for most of the speed differential. One must also consider that ship winds are usually measured at heights of 20 - 30 m above the sea and consequently their reports often exceed those from a perfectly exposed anemometer at the standard height of 10 m. Use of the power law formula of Schmidt (23) indicates that both Sable Island and Grindstone Island records would result in winds of about 15.6 kt at a height of 25 m. On this basis, one should consider that the winds at Grindstone used in the following analysis are about 5% higher than those encountered by ships in adjacent areas of the Gulf. There should be no bias regarding direction reported.

In the following summary **GALE** refers to wind speeds of 28 - 47 kt, **STORM** to those with speeds of 48 - 62 kt and **HURRICANE** to those exceeding 62 kt. All cases were examined when the wind exceeded 26 kt for 6 hours or more, exceeded 48 kt for 3 hours or more, or exceeded 62 kt for one hour. The intent was to eliminate the brief squalls which just enter the gale force range. The summations are partially cumulative for the gale force summations refer to those periods when the winds reached gale force but did not enter the storm range (remained under 48 kt). The storm winds include the build-up gales for this focuses attention on the total interval of the stronger winds which led to the storm itself. Similarly at the hurricane force level the period of storm and gales are listed.

NOVEMBER

In 40 years of data there were 260 gales reported, an average of about 6.5 per year.

(a) For 247 of these occurrences (96%) the wind remained in the 28 - 47 kt range with an average duration of 12 hours and a maximum duration of 36 hours. The breakdown by quadrant was 38% from N-NW, 26% S-SE, 21% from W-SW and 15% from E-NE.

(b) On 10 occasions in the 40 years the winds rose to the 48 - 62 kt range for a total duration of 74 hours. Associated with these particular periods there were also 91 hours in the gale force range. Maximum continuous duration in the storm ranges was 18 hours and in the gale force range, 43 hours. Averages are 8 and 11 hours respectively and these are cumulative, i.e. winds were in the 28 - 62 kt range for an average of 19 hours. 5 of the storms were from the N-NW quadrant and there was 1 each from the other three quadrants.

(c) On 3 occasions the winds reached hurricane force, twice for a 3 hour duration and once for 19 hours. Associated with these violent winds were a total of 49 hours in the storm force range and another 86 hours of gales. The total durations above 32 kt were thus 42 hours (from W-SW), and 27 and 91 hours both from N-NW. Maximum hourly wind was 71 kt.

DECEMBER

In 40 years there were 321 gales reported, an average of 7.3 per year.

(a) On 291 occasions (91%) the wind remained in the 28 - 47 kt range with an average duration of 13 hours and a maximum of 54 hours. The breakdown by quadrant was N-NW 46%, W-SW 27%, S-SE 18%, and E-NE 9%.

(b) On 25 occasions in the 40 years, winds reached the storm category for a total duration of 144 hours (average 6 hours, maximum 13 hours). Besides these durations there was an average of 19 hours of gale force winds associated (minimum 6 hours, maximum 35 hours).

(c) On 5 occasions in the 40 years, winds reached hurricane force. One 4-hour period from the W-SW was accompanied by 27 hours of storm force and 38 hours of gale force winds for a total duration of 69 hours. There were 4 separate occasions with N-NW winds totalling 5 hours. They had a total of 28 hours of storm force and 56 hours of gale force winds, making average duration of associated storms from this direction 7 hours and of gales 14 hours.

JANUARY

There were 298 occasions of winds over 28 kt, about 7.5 per year.

(a) On 269 occasions (92%) the winds remained in the gale force range with an average duration of 13.7 hours and a maximum of 104 hours. The breakdown by quadrant is N-NW 52%, W-SW 25%, S-SE 16% and E-NE 7%.

(b) On 27 occasions in the 40 years winds reached storm force for a total duration of 137 hours. Associated with these periods were an additional 439 hours of gales. The durations thus average 6 hours storm force (maximum 17 hours) and an additional 21 hours of gales (maximum 33 hours).

(c) On 2 occasions winds reached hurricane force: Once from the S-SE quadrant for 1 hour associated with 11 hours of storm force and 25 hours of gale force winds, and another one from the N-NW quadrant for 3 hours associated with 10 hours of storm and 10 hours of gale force winds.

FEBRUARY

There were 205 occasions of winds over 28 kt, about 5 per year.

(a) On 185 occasions (90%) the winds remained in the gale force range with an average duration of 12.4 hours and a maximum of 47 hours. The breakdown by quadrant was N-NW 47%, S-SW 23%, S-SE 21%, and E-NE 9%.

(b) On 16 occasions in the 40 years winds reached storm force for a total duration of 96 hours. Associated with these periods were 283 hours of gale force winds. The duration thus averaged 6 hours of storm force and nearly 18 additional hours of gale force winds.

(c) On 4 occasions winds reached hurricane force and each time they were from the N-NW quadrant. The total duration was 19 hours and the maximum in one event was 12 hours. Associated with these four occurrences was a total of 61 hours of storm force winds (maximum 38 hours on one occasion) and 85 hours of gale force winds (maximum 49 hours).

MARCH

There were 163 gales: an average of 4 per year.

(a) On 152 occasions (94%) the winds remained below 48 kt with an average duration of 12.4 hours and a maximum of 41. The direction breakdown is N-NW 42%, W-SW 26%, S-SE 18%, E-NE 14%.

(b) On 10 occasions the winds reached storm force for a total duration of 81 hours. (Average 8, maximum 27 hours). Associated with these winds were an additional 238 hours of gale force winds (average 24 hours, maximum 84).

(c) On one occasion winds reached hurricane force (from the N-NW) for 10 hours and there were, in addition, 14 hours of storm force winds and 30 hours of gale force.

APRIL

There were 139 gales, an average of 3.5 per year.

(a) On 133 occasions (96%) the speed remained in the 28 - 47 kt range with an average duration of 12.5 hours. 41% of the time from the N-NW, 23% each from the S-SE and E-NE and only 13% from the W-SW.

(b) On 6 occasions winds reached storm force for a total duration of 35 hours. Associated were 105 hours of gale force winds (average duration 18 hours, maximum 26).

(c) No hurricane force winds occurred in the 40 years examined; the maximum hourly winds recorded were 61 kts (70 mph).

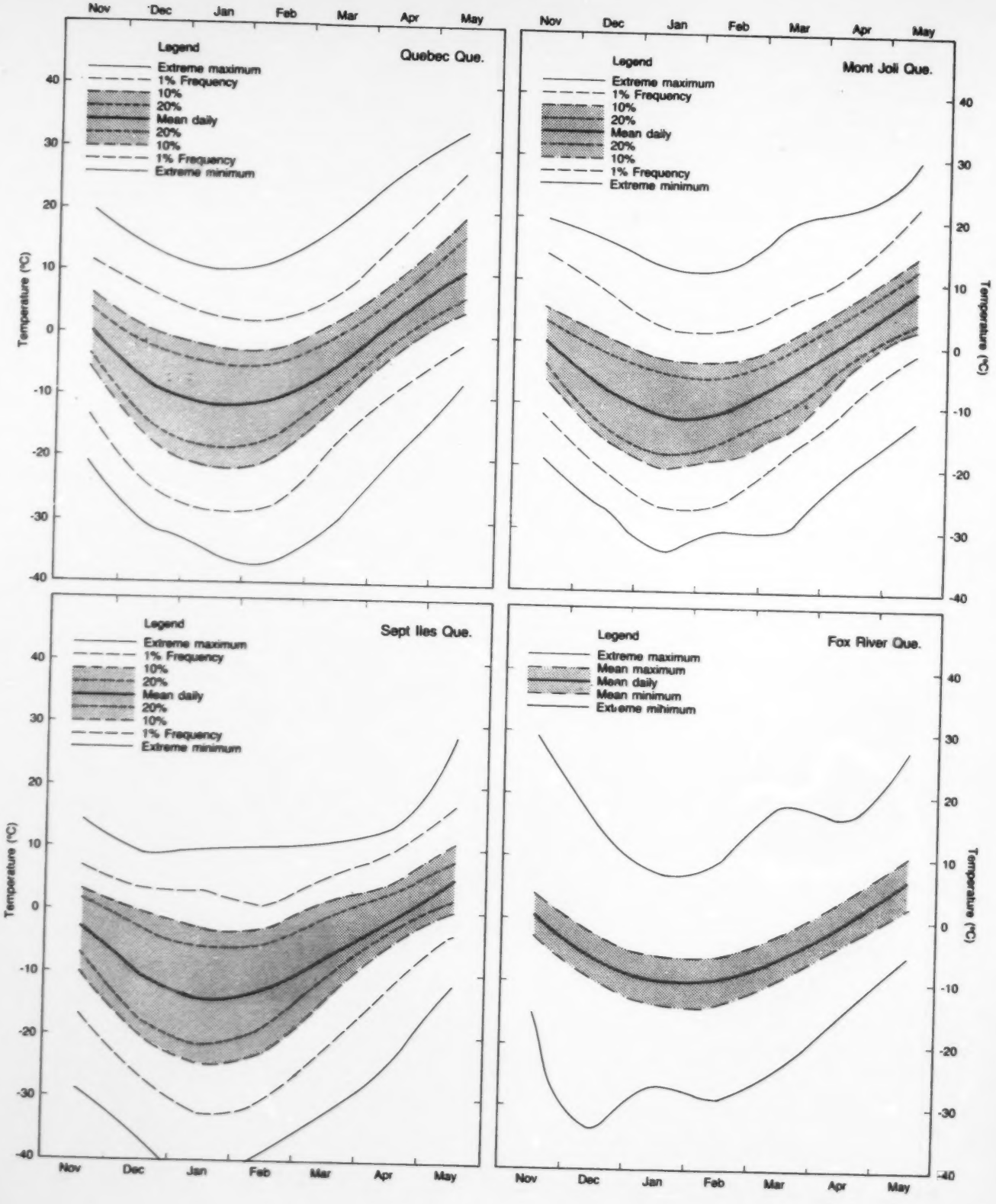
A few instances of gale force winds are not included in this analysis because of their short duration from a specific direction. For instance, a northerly gale of 4 hours followed by a northwest or westerly gale of up to five hours would not be included because the 6-hour limit in one direction was not exceeded. Another type of situation is excluded in the summations and this arises when the wind shifts just before a gale subsides. Some of the two-or three-hour gales may be continuations of a longer gale from another direction.

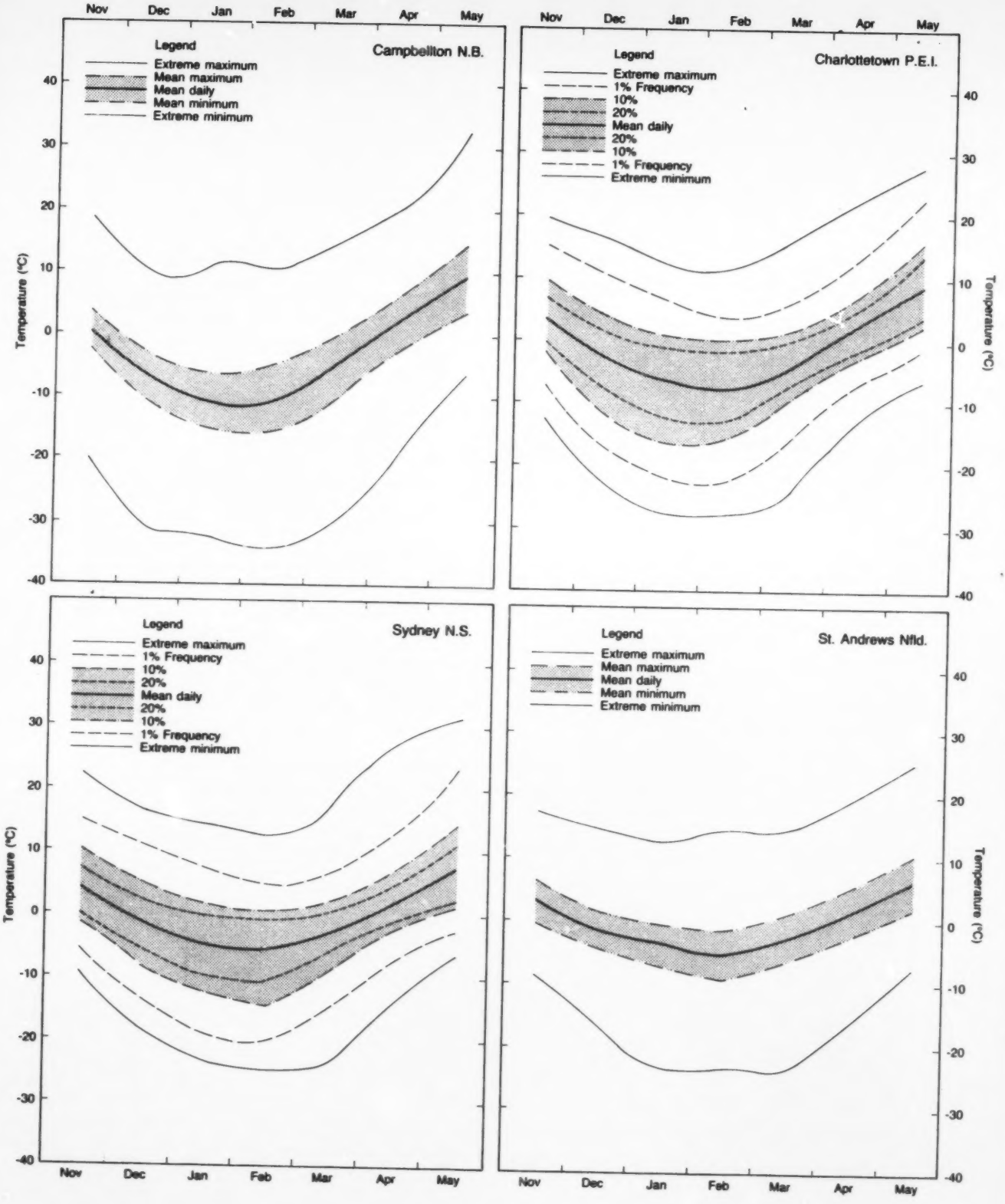
The total duration of these and other brief one-or two-hour winds of gale force averaged 32 hours in December, 29 in January and decreased gradually to 19 in April.

For storms the duration studied was 3 hours or more and consequently the omitted hours were only 1 - 2 per month and averaged less than one hour in April.

SUMMATION OF OCCURRENCE OF HOURLY WINDS OVER 28 KNOTS

	Total Occasions in 40 Years				Total Number of Hours				
	Over 62 kt	62-48 kt	47-28 kt	Freq. per yr.	Over 62 kt	62-48 kt	47-28 kt	Total Duration Over 28 kt	Average Duration
NOV.	3	10	247	1 in 13 yrs 1 in 4 yrs 6.2/yr	25	49 74	86 91 3073	160 165 3073	53.3 17.0 12.4
DEC.	5	25	291	1 in 8 yrs 1 in 2 yrs 7.3/yr	12	55 144	91 441 3777	158 585 3777	31.6 23.4 13.0
JAN.	2	27	269	1 in 20 yrs 1 in 2 yrs 6.8/yr	4	21 137	35 439 3687	60 576 3687	30.0 26.2 13.7
FEB.	4	16	185	1 in 10 yrs 1 in 2½ yrs 4.7/yr	19	61 96	85 283 2302	165 379 2302	41.2 23.7 12.4
MAR.	1	10	152	1 in 40 yrs 1 in 4½ yrs 3.8/yr	10	14 81	30 238 1886	54 319 1886	54.0 31.9 12.4
APR.	0	6	133	0 1 in 7 yrs 1.4/yr		35	105 1663	140 1663	23.3 12.5
TOTALS AVERAGE HRS PER YEAR	15	94	1277		70 1.75	767 19	18312 458	19149 479	


Quebec Que.
Legend
Extreme maximum
1% Frequency
10%
20%
Mean daily
20%
10%
1% Frequency
Extreme minimum
Mont Joli Que.
Sept Iles Que.
Fox River Que.
Mean maximum
Mean daily
Mean minimum
Extreme minimum
Nov
Dec
Jan
Feb
Mar
Apr
May
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40


Campbellton N.B.
Legend
Extreme maximum
Mean maximum
Mean daily
Mean minimum
Extreme minimum
Charlottetown P.E.I.
Legend
Extreme maximum
1% Frequency
10%
20%
Mean daily
20%
10%
1% Frequency
Extreme minimum
Sydney N.S.
Legend
Extreme maximum
1% Frequency
10%
20%
Mean daily
20%
10%
1% Frequency
Extreme minimum
St. Andrews Nfld.
Legend
Extreme maximum
Mean maximum
Mean daily
Mean minimum
Extreme minimum
Nov
Dec
Jan
Feb
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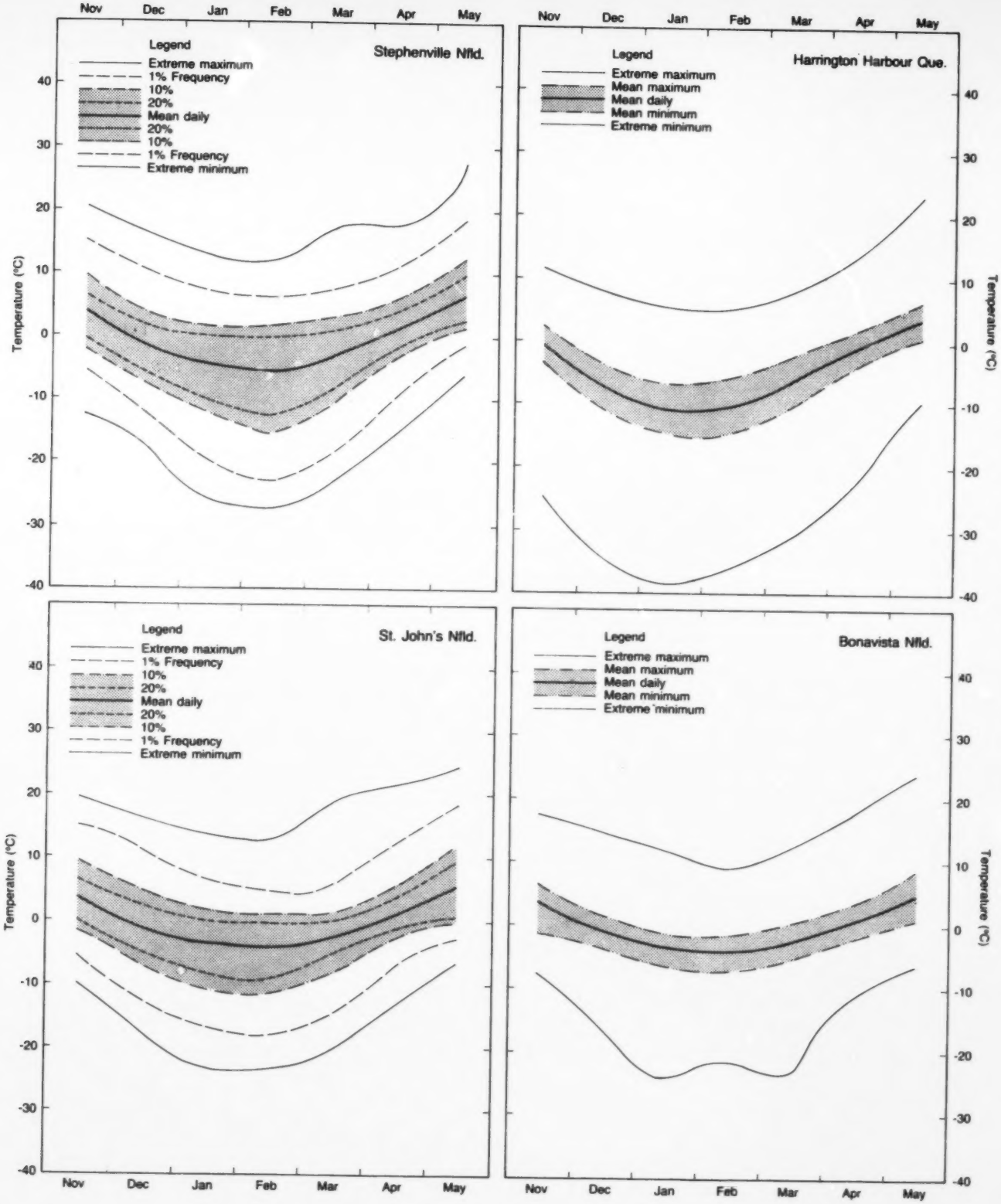
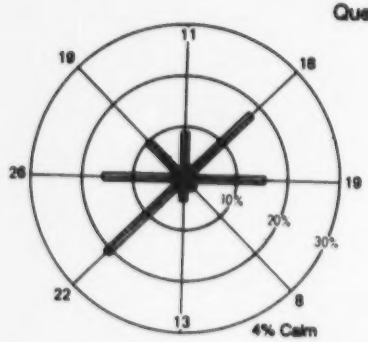
May
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40

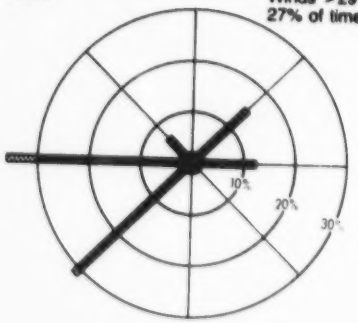

Nov
Dec
Jan
Feb
Mar
Apr
May
Legend
Extreme maximum
1% Frequency
10%
20%
Mean daily
20%
10%
1% Frequency
Extreme minimum
Stephenville Nfld.
Harrington Harbour Que.
St. John's Nfld.
Bonavista Nfld.
Mean maximum
Mean minimum
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40

JANUARY

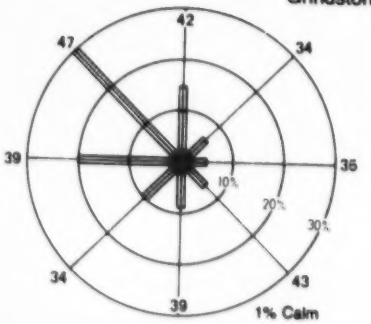
Quebec Que.



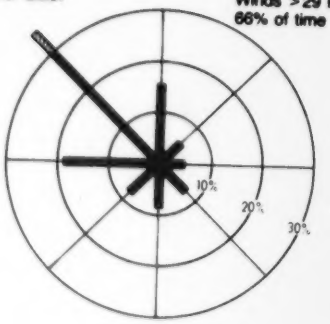
Winds > 29 km/h
27% of time



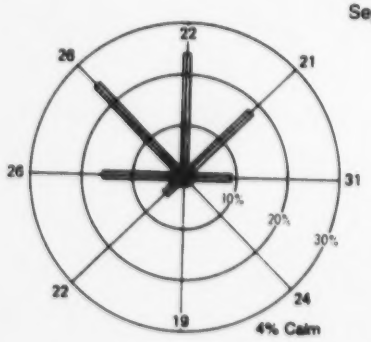
Grindstone Island Que.



Winds > 29 km/h
66% of time

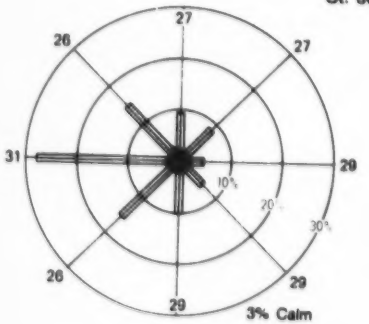


Sept Iles Que.



Winds > 29 km/h
30% of time

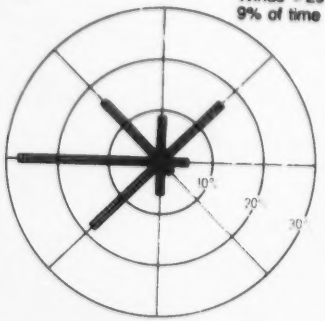
St. John's Nfld.



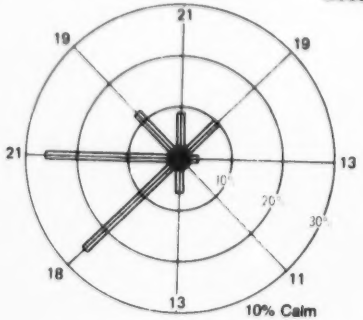
Winds > 29 km/h
38% of time

Chatham N.B.

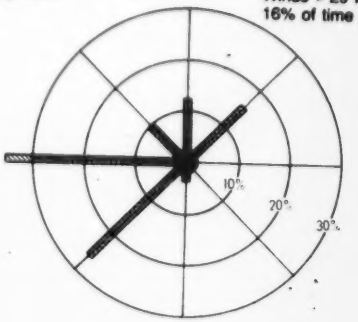
Winds > 29 km/h
9% of time



Goose Bay Lab.



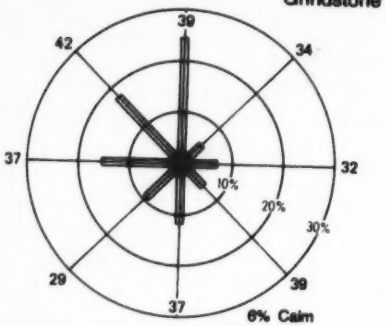
Winds > 29 km/h
16% of time



FEBRUARY

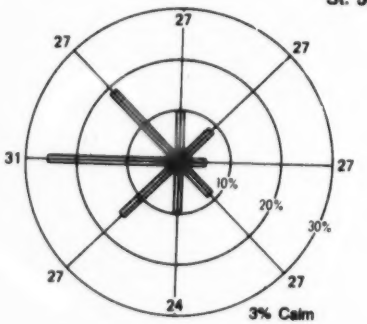
Quebec Que.

Grindstone Island Que.

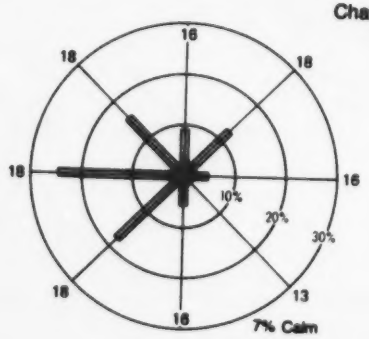


Sept Iles Que.

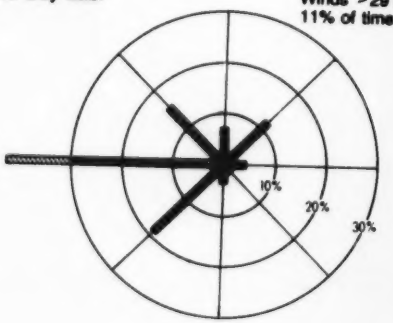
St. John's Nfld.

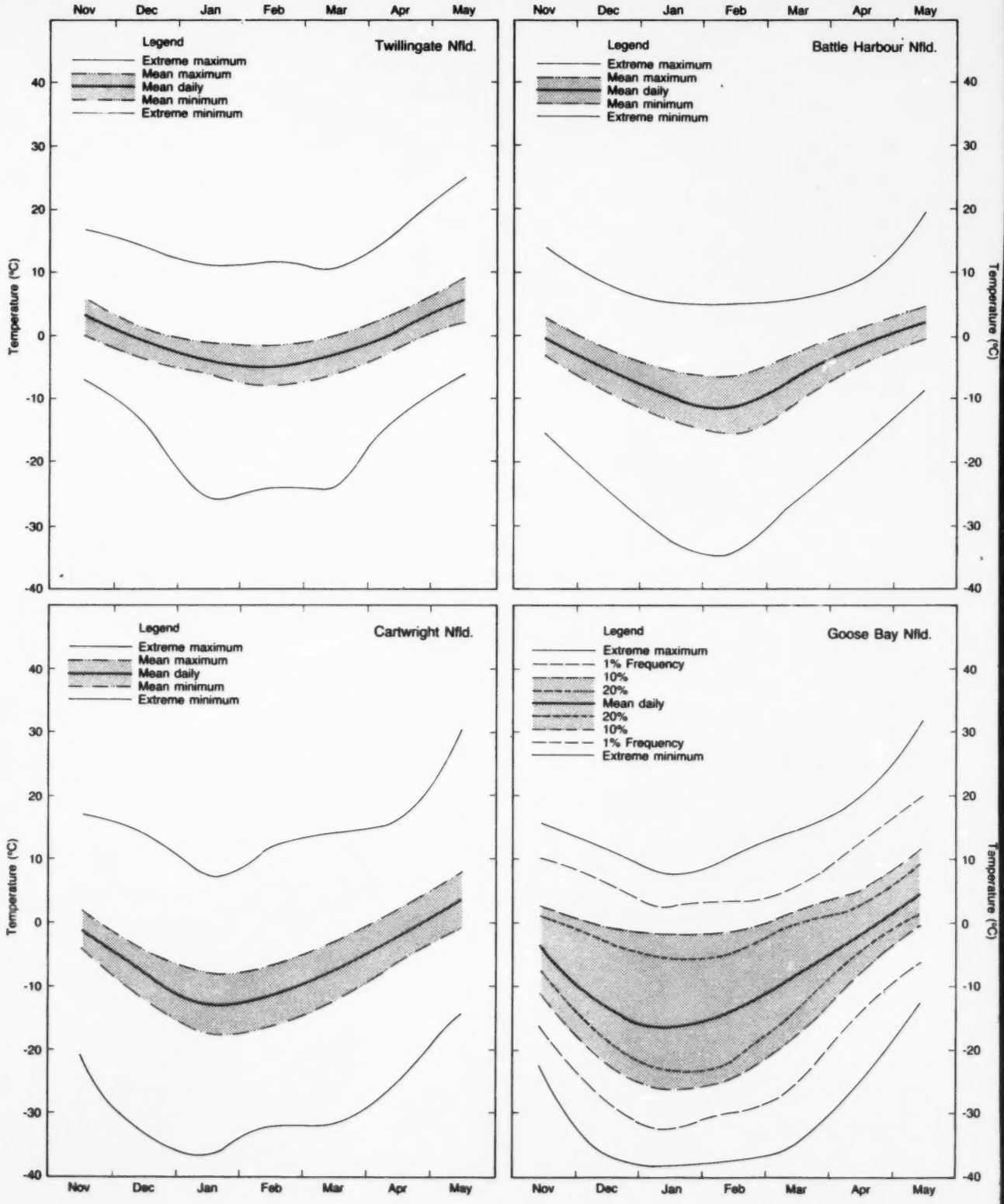


Chatham N.B.



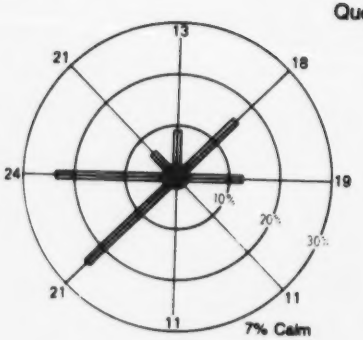
Goose Bay Lab.




Nov
Dec
Jan
Feb
Mar
Apr
May
Twillingate Nfld.
Battle Harbour Nfld.
Cartwright Nfld.
Goose Bay Nfld.
Legend
Extreme maximum
Mean maximum
Mean daily
Mean minimum
Extreme minimum
1% Frequency
10%
20%
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40

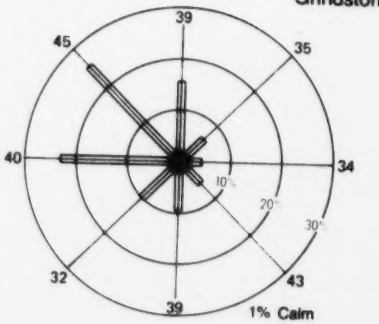
DECEMBER

Quebec Que.

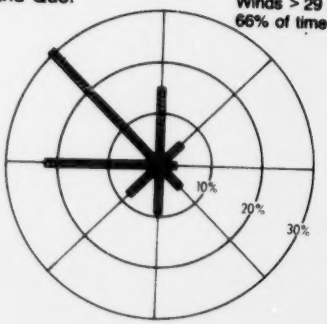


Winds > 29 km/h
22% of time

Grindstone Island Que.

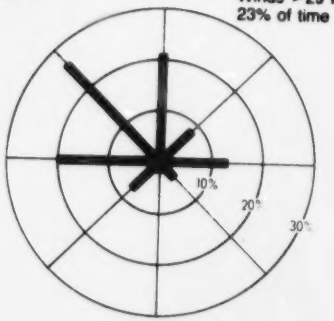


Winds > 29 km/h
66% of time

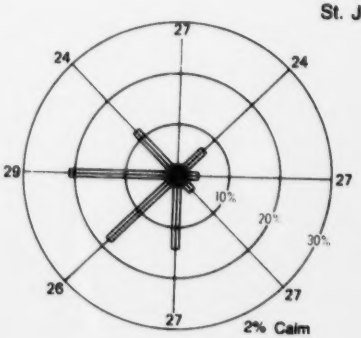


Sept Iles Que.

Winds > 29 km/h
23% of time



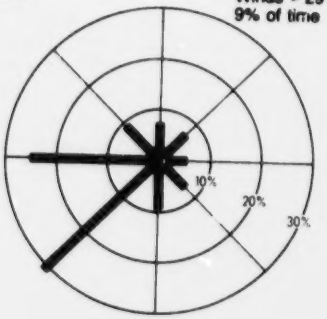
St. John's Nfld.



Winds > 29 km/h
33% of time

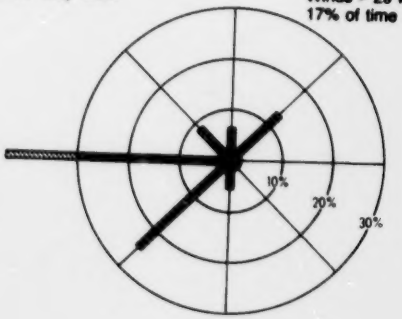
Chatham N.B.

Winds > 29 km/h
9% of time



Goose Bay Lab.

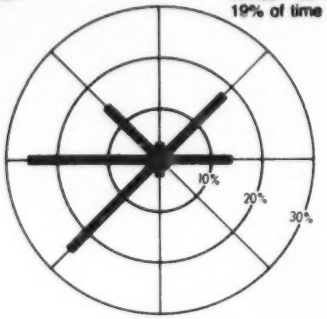
Winds > 29 km/h
17% of time



MARCH

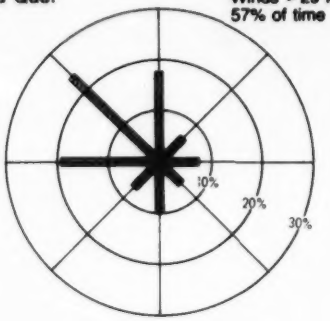
Quebec Que.

Winds > 29 km/h
19% of time



Grindstone Island Que.

Winds > 29 km/h
57% of time

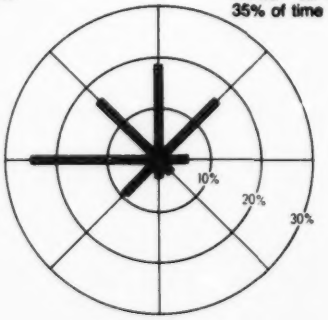


Sept Iles Que.

Winds > 29 km/h
28% of time

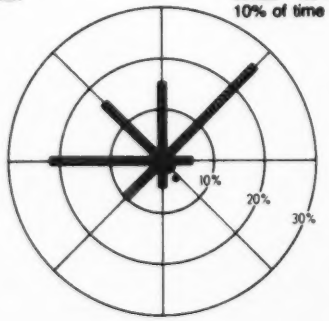
St. John's Nfld.

Winds > 29 km/h
35% of time



Chatham N.B.

Winds > 29 km/h
10% of time



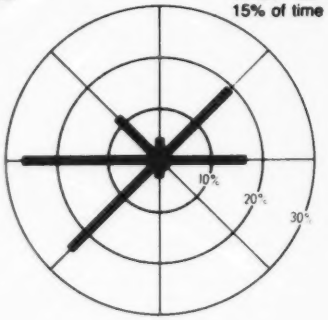
Goose Bay Lab.

Winds > 29 km/h
12% of time

APRIL

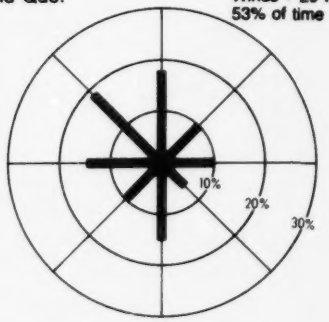
Quebec Que.

Winds > 29 km/h
15% of time



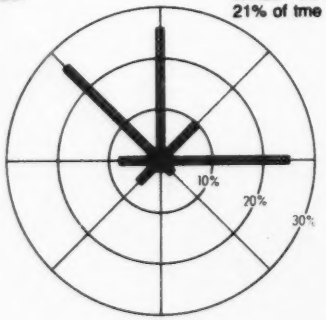
Grindstone Island Que.

Winds > 29 km/h
53% of time



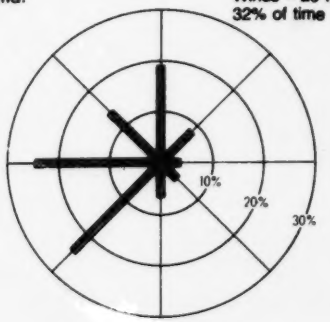
Sept Iles Que.

Winds > 29 km/h
21% of tme



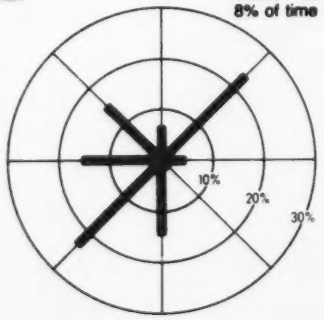
St. John's Nfld.

Winds > 29 km/h
32% of time



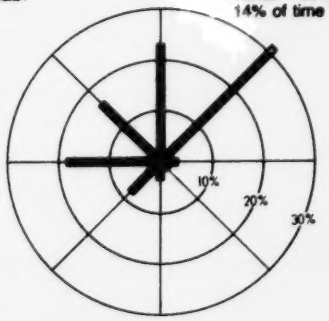
Chatham N.B.

Winds > 29 km/h
8% of time



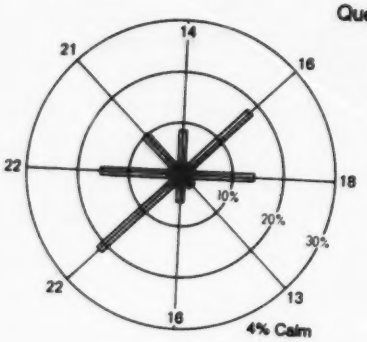
Goose Bay Lab.

Winds > 29 km/h
14% of time

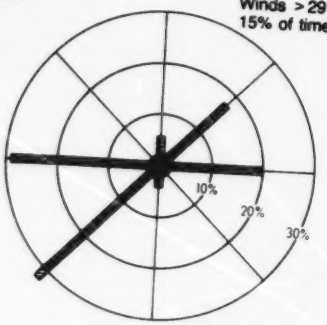


MAY

Quebec Que.



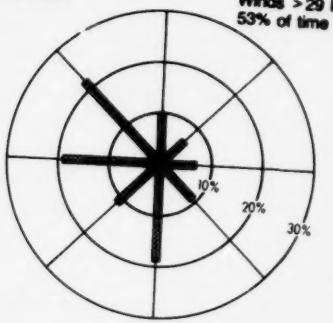
4% Calm



Winds > 29 km/h
15% of time

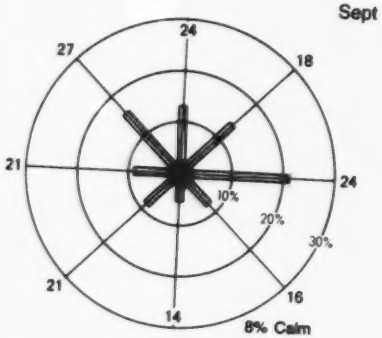
Grindstone Island Que.

• Calm

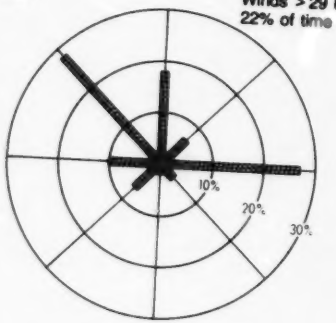


Winds > 29 km/h
53% of time

Sept Iles Que.

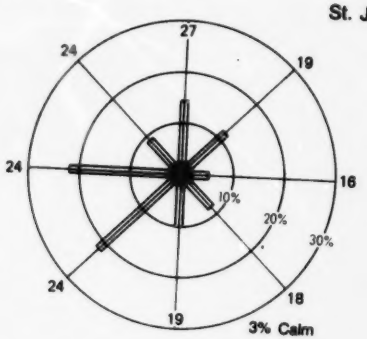


8% Calm

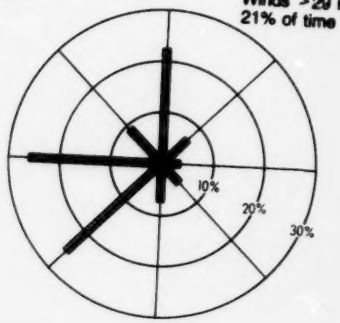


Winds > 29 km/h
22% of time

St. John's Nfld.

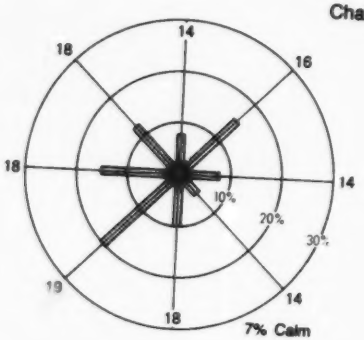


3% Calm

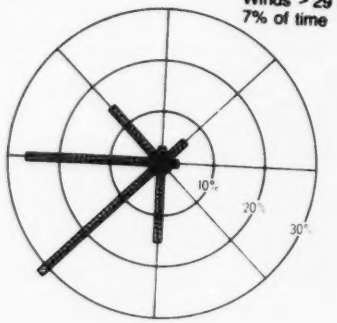


Winds > 29 km/h
21% of time

Chatham N.B.

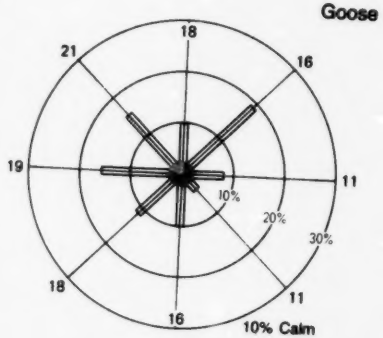


7% Calm

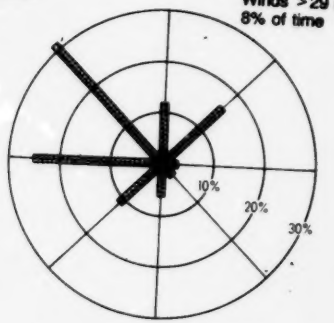


Winds > 29 km/h
7% of time

Goose Bay Lab.



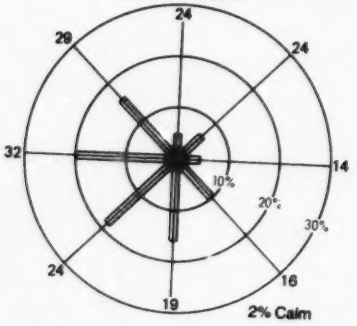
10% Calm



Winds > 29 km/h
8% of time

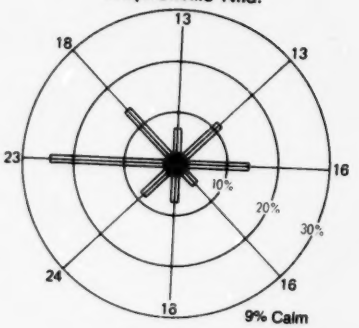
DECEMBER

Mont Joli Que.

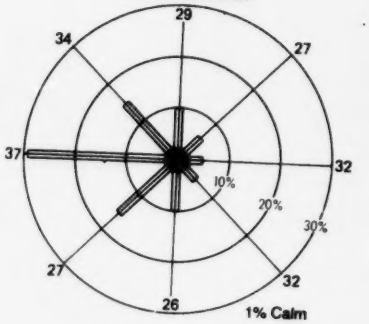


Fox River Que.

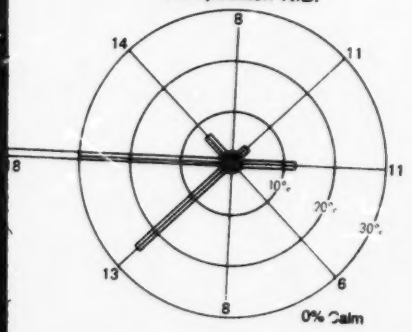
Stephenville Nfld.



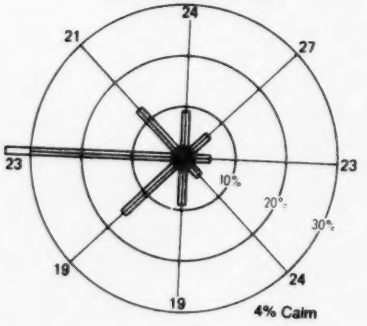
Bonavista Nfld.



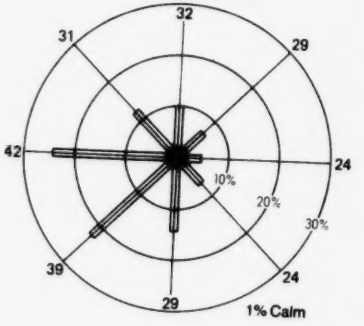
Campbellton N.B.



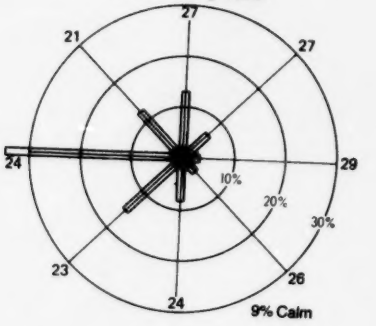
Charlottetown P.E.I.



Twillingate Nfld.



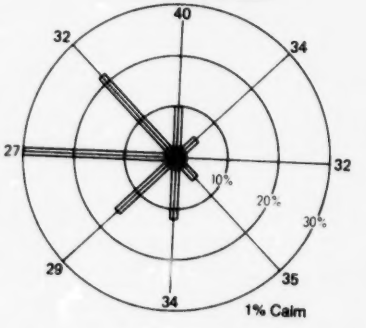
St. Anthony Nfld.



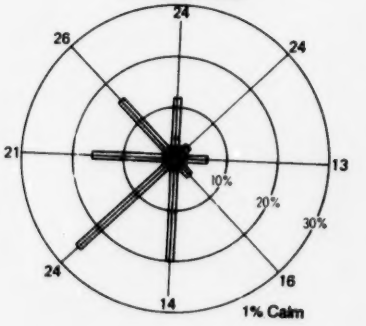
Sydney N.S.

St. Andrews Nfld.

Battle Harbour Lab.



Cartwright Lab.



JANUARY

Mont Joli Que.

3% Calm

Fox River Que.

0% Calm

Stephenville Nfld.

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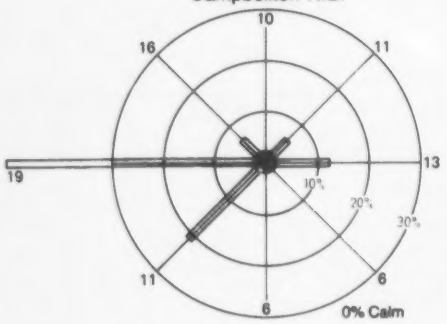

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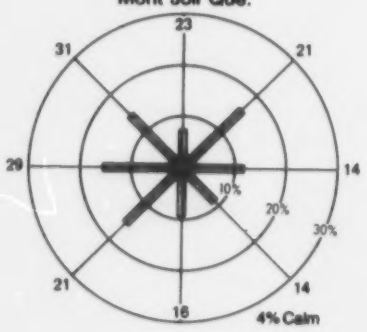

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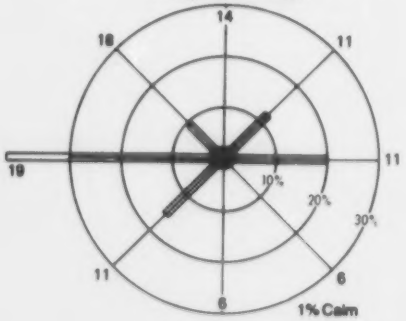

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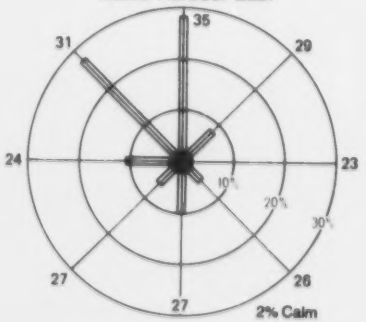

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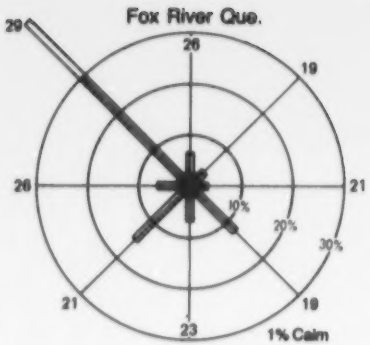
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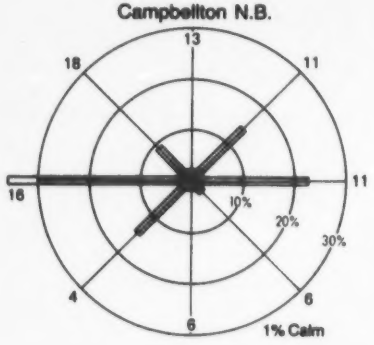
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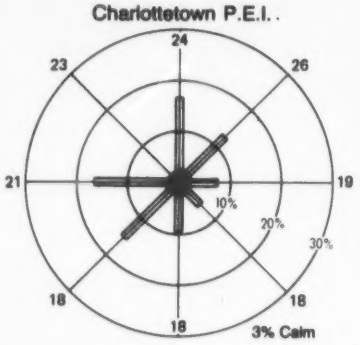
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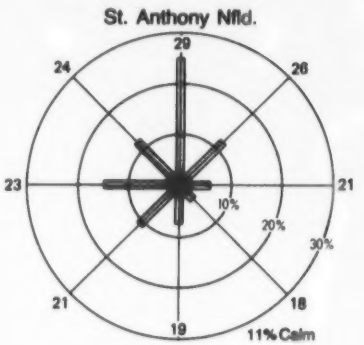
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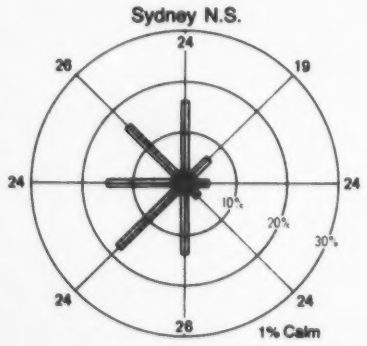
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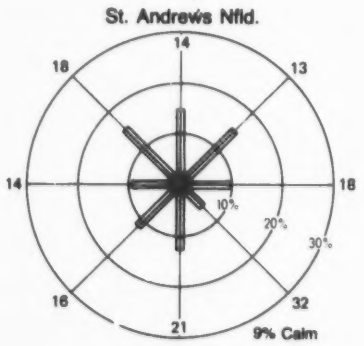
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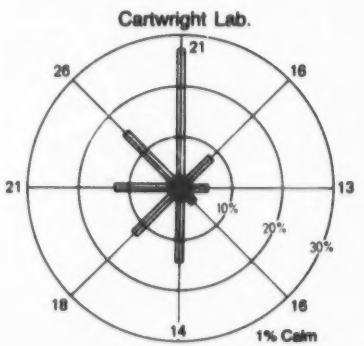
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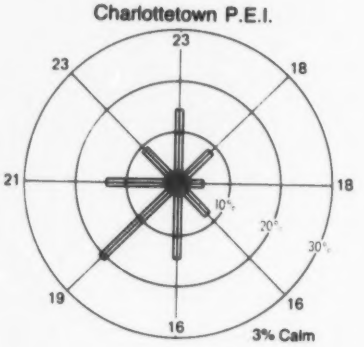
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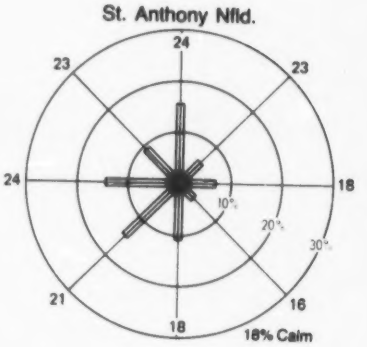
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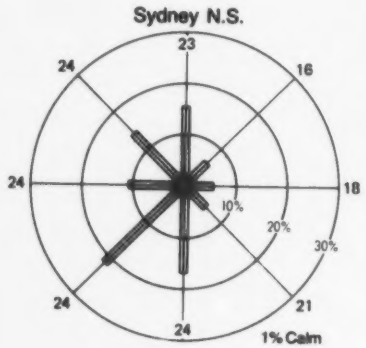
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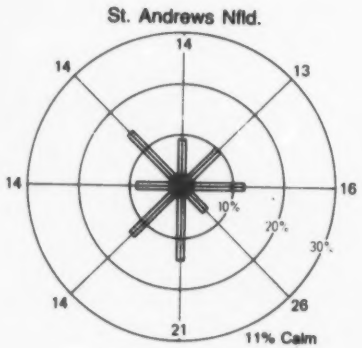
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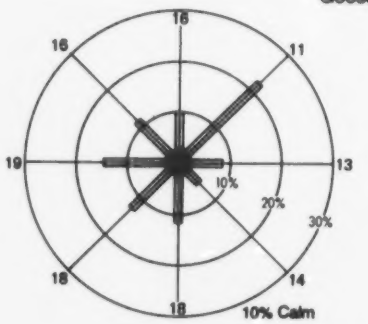

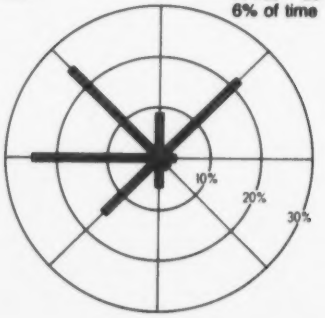

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Appendix A

TERMINOLOGY

The complete International Ice Terminology of the World Meteorological Organization includes almost two hundred terms related to ice-covered seas. Many of them are self-explanatory, others are used primarily in glacial areas and some are intended for specific users, e.g. submariners. The following lists include those terms in common use and a few that are expected to become so in the near future. Illustrations of the major ice classifications, concentration categories etc., as seen from shipboard follow the definitions.

1. **Ages of Ice (Development)**

New Ice – A general term for recently formed ice which includes **Frazil Ice, Grease Ice, Slush** and **Shuga.** These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

Frazil ice – Fine spicules or plates of ice suspended in water.

Grease ice – A later stage of freezing than **Frazil ice** when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matte appearance (Figure 10).

Slush – Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

Shuga – An accumulation of spongy white ice lumps a few centimetres across, formed from **grease ice** or **slush** and sometimes from **anchor ice** rising to the surface.

Nilas – A thin, elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" (finger rafting). Has a matte surface and is up to 10 cm in thickness.

Dark Nilas – Nilas which is under 5 cm in thickness and is very dark in colour.

Light Nilas – Nilas which is more than 5 cm in thickness and rather lighter in colour than **dark nilas.**

Ice Rind – A brittle shiny crust of ice formed on a quiet surface by direct freezing or from **grease ice,** usually in water of low salinity. Thickness to about 5 cm. Easily broken by wind or swell, commonly breaking into rectangular pieces.

Young Ice – Ice in the transition stage between **nilas** and **First-Year ice,** 10 to 30 cm in thickness. May be subdivided into **Grey ice** and **Grey-White ice.**

Grey Ice – **Young ice** 10 - 15 cm thick. Less elastic than **nilas** and breaks on swell. Usually rafts under pressure. (Figure 11, 12).

Grey-White Ice – **Young ice** 15 - 30 cm thick. Under pressure more likely to ridge than to raft. (Figure 13).

First-Year Ice – Sea ice of not more than one winter's growth, developing from **young ice**; thickness from 30 cm to 2 m.

Thin – **First-year ice** 30 - 70 cm thick. May also be called **White Ice.** (Figure 16).

Medium – **First-year ice** 70 - 120 cm thick.

Thick – **First-year ice** over 120 cm thick.

Old Ice – Sea ice which has survived at least one summer's melt. Most topographic features are smoother than on first-year ice.

Second-Year Ice – **Old ice** which has survived only one summer's melt. Because it is thicker and less dense than **first-year ice,** it stands higher out of the water. In contrast to **multi-year ice,** summer melting produces a regular pattern of numerous small **puddles.** Bare patches and **puddles** are usually greenish-blue.

Multi-year Ice – **Old ice** up to 3 m or more thick which has survived at least two summers. **Hummocks** smoother than in **second-year ice**, and the ice is almost salt free. Colour, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system.

2. **Forms of Fast Ice**

Fast Ice – Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals of grounded icebergs. Vertical fluctuations may be observed during changes of sea level. Fast ice may be formed "in situ" from sea water or by freezing of pack ice of any age to the shore, and it may extend a few metres or several hundred kilometres from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category (old, second-year, or multi-year). If it is thicker than about 2 m above sea level it is called an ice shelf.

Icefoot – A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the fast ice has moved away.

Anchor Ice – Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation.

Stranded Ice – Ice which has been floating and has been deposited on the shore by retreating high water.

Grounded Ice – Floating ice which is aground in shoal water (cf. stranded ice).

3. **Forms of Pack Ice**

Pack Ice – Term used in a wide sense to include any area of sea ice, other than fast ice, no matter what form it takes or how it is disposed.

Ice Cover – The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic locale. This locale may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

Concentration – The ratio expressed in tenths or oktas describing the mean areal density of ice in a given area.

Compact Pack Ice – Pack ice in which the concentration is 10/10 and no water is visible. (Figure 24).

Consolidated Pack Ice – Pack ice in which the concentration is 10/10 and the floes are frozen together. (Figure 24).

Very Close Pack Ice – Pack ice in which the concentration is 9/10 to less than 10/10. (Figure 23).

Close Pack Ice – Pack ice in which the ice concentration is 7/10 to 8/10, composed of floes mostly in contact. (Figure 22).

Open Pack Ice – Pack ice in which the concentration is 4/10 to 6/10, with many **leads** and **polynyas**, and the floes are generally not in contact with one another. (Figure 21).

Very Open Pack Ice – Pack ice in which the concentration is 1/10 to 3/10, and water preponderates over ice. (Figure 20).

Open Water – A large area of freely navigable water in which sea ice is present in concentration less than 1/10. There may be ice of **land origin** present, although the total concentration of all ice shall not exceed 1/10. (Figure 19).

Bergy Water – An area of freely navigable water with no sea ice present but in which ice of land origin is present.

Ice Free – No sea ice present. If ice of any kind is present this term should not be used.

4. **Floe Size**

Giant Floe – Over 10 km (6n.m) across.

Vast Floe – 2 - 10 km (1-6n.m) across.

Big Floe – 500 - 2,000 m across.

Medium Floe – 100 - 500 m across.

Small Floe – 20 - 100 m across.

Ice Cake – Under 20 m across.

Brash Ice – Under 2 m across.

5. **Arrangement**

Ice Field – Area of pack ice consisting of any size of floes which is greater than 10 km across (cf. patch).

Ice Patch – An area of pack ice less than 10 km across (Figure 15).

Ice Massif – A concentration of sea ice covering hundreds of square kilometres, which is found in the same region every summer.

Belt – A large feature of pack ice arrangement; longer than it is wide; from 1 km to more than 100 km in width.

Tongue – A projection of the ice edge up to several kilometres in length, caused by wind or current.

Strip – Long, narrow area of pack ice, about 1 km or less in width usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell or current. (Figure 8).

Ice Jam – An accumulation of broken river ice, or sea ice caught in a narrow channel.

Ice Edge – The demarcation at any given time between the open sea and sea ice of any kind whether fast or drifting. It may be termed compacted or diffuse (cf. ice boundary).

Compact Ice – Close, clear-cut ice edge compacted by wind or current; usually on the windward edge of an area of pack ice. (Figure 15).

Diffuse Ice Edge – Poorly defined ice edge limiting an area of dispersed ice; usually on the leeward side of an area of pack ice.

Ice Limit – Climatological term referring to the extreme minimum or extreme maximum extent of the ice edge in any given month or period based on observations over a number of years. Term should be preceded by minimum or maximum (cf. mean ice edge).

Mean Ice Edge – Average position of the ice edge in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge (cf. ice limit).

Fast Ice Edge – The demarcation at any given time between fast ice and open water.

Fast-Ice Boundary – The ice boundary at any given time between fast ice and pack ice.

6. **Motion Processes**

Diverging – Ice fields or floes in an area are subjected to diverging or dispersive motion, thus reducing ice concentration and/or relieving stresses in the ice.

Compacting – Pieces of floating ice are said to be compacting when they are subjected to a converging motion, which increases ice concentration and/or produces stresses which may result in ice deformation.

Shearing – An area of pack ice is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a flaw (q.v.)

7. **Openings in the Ice**

Fracture – Any break or rupture through **very close pack ice, consolidated pack ice, fast ice,** or a single floe resulting from deformation processes. Fractures may contain **brash ice** and/or be covered with **nilas** and/or **young ice.** Length may vary from a few metres to many kilometres.

Very Small Fracture – 0 - 50 m wide.

Small Fracture – 50 - 200 m wide.

Medium Fracture – 200 - 500 m wide.

Large Fracture – More than 500 m wide.

Crack – Any fracture which has not parted.

Tide Crack – Crack at the line of junction between an immovable **ice foot** or **ice wall** and **fast ice,** the latter subject to the rise and fall of the tide.

Flaw – A narrow separation zone between **pack ice** and **fast ice,** where the pieces of ice are in chaotic state. It forms when pack ice shears under the effect of a strong wind or current along the fast ice boundary (cf. shearing).

Lead – Any fracture or passage way through sea ice which is navigable by surface vessels.

Polynya – Any non-linear shaped opening enclosed in ice. Polynyas may contain **brash ice, nilas** or **young ice.** Submariners refer to these as skylights. Sometimes the polynya is limited to one side by the coast and is called a **shore polynya** or by fast ice and is called a **flaw polynya.** If it recurs in the same position every year, it is called a **recurring polynya.**

8. **Ice-surface Features**

Level Ice – Sea ice which is unaffected by deformation.

Deformed Ice – A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are **rafted ice, ridged ice** and **hummocked ice.**

Rafted Ice – Type of deformed ice formed by one piece of ice overriding another (cf. finger rafting). (Figure 17).

Finger-rafted Ice – Type of rafted ice in which floes thrust ''fingers'' alternately over and under the other.

Ridge – A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge forced downwards by pressure is termed an **ice keel.** (Figure 18).

New Ridge – Ridge newly formed with sharp peaks and slope of sides usually 40°. Fragments are visible from the air at low altitude.

Weathered Ridge – Ridge with peaks slightly rounded and slope of sides usually 30 to 40°. Individual fragments are not discernible.

Aged Ridge – Ridge which has undergone considerable weathering. These ridges are best described as undulations.

Hummock – A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure is termed a **bummock.** (Figure 18).

Ram – An underwater ice projection from an **ice wall, ice front, iceberg** or **floe.** Its formation is usually due to a more intensive melting and erosion of the unsubmerged part.

9. **Stages of Melting**

Puddle – An accumulation on ice of melt-water, mainly due to melting snow, but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow. (Figure 16).

Thaw Holes – Vertical holes in sea ice formed when surface puddles melt through to the underlying water.

Rotten Ice – Sea ice which has become honeycombed and which is in an advanced state of disintegration.

10. **Ice of Land origin**

Iceberg – A massive piece of ice of greatly varying shape, more than 5 m above sea level, which has broken away from a glacier, and which may be afloat or aground. Icebergs may be described as tabular, dome-shaped, sloping, pinnacled, weathered or glacier bergs. (Figure 25).

Tabular Berg – A flat-topped iceberg. Most tabular bergs are formed by calving from an ice shelf and show horizontal banding (cf. **ice island**).

Ice Island – A large piece of floating ice about 5 m above sea level, which has broken away from an Arctic ice shelf, having a thickness of 30-50 m and an area of from a few thousand square metres to 500 sq km or more, and usually characterized by a regular undulating surface which gives it a ribbed appearance from the air.

Bergy Bit – A large piece of floating glacier ice, generally showing less than 5 m above sea level but more than 1 m and normally about 100-300 sq m in area. (Figure 26).

Growler – Smaller piece of ice than a **bergy bit** or floeberg. Often transparent but appearing green or almost black in colour, extending less than 1 m above the surface and normally occupying an area of about 20 sq m. (Figure 27).

11. **Miscellaneous**

Water Sky – Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity of sea ice.

Beset – Situation of a vessel surrounded by ice and unable to move.

Icebound – A harbour, inlet, etc. is said to be icebound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker.

Nip – Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped.

Figure 10 – Grease Ice

The presence of this initial form of ice is usually detected by the absence of ripples and the oily appearance of the sea. The ice-covered area appears white in this photograph; in reality the oiliness of the surface is quite apparent but its color varies with differing cloud conditions.

Figure 11 – Nilas and Grey Ice

The very straight edge of the ice where the icebreaker appears to have torn her way through, as well as the absence of cracks from the bow wave are typical of nilas ice. In the middle-ground a floe of grey ice is evident while further back there appear some grey-white or white floes.

Figure 12 – Grey and White Ice

In the fore-ground there are a few grey coloured floes in a typical round pancake form with raised rims. In the left middle ground is a larger floe of white ice which has formerly been under considerable pressure, and many of the smaller floes also carry various sized ice cakes and brash as a result of earlier deformations. Slow refreezing appears to be under way in the right foreground and is probably occurring everywhere in the scene.

Figure 13 – Grey-White Ice
The presence of a dry snow cover and the evidence of small ridges on many of the floes indicate that the ice here is in the 15-30 cm range making it grey-white type. In the background, grey ice or nilas seems to predominate.

Figure 14 – An aerial view of the pack ice edge showing various strips and patches of very close pack with nearly open water between them. This is typical of an area where the wind has a component from the ice to the open sea.

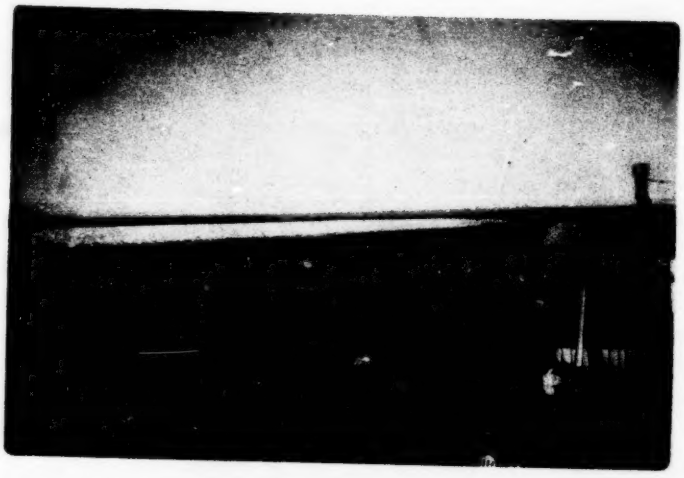


Figure 15 – A shipboard view of an ice patch with a well-defined edge.

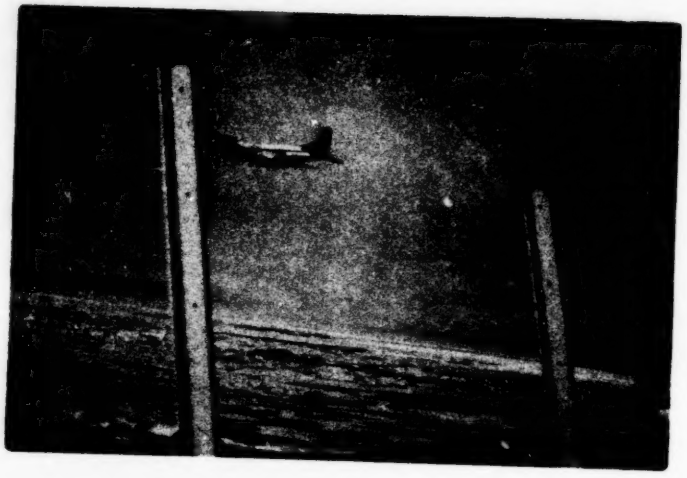


Figure 16 – First-Year Ice with Puddles
The ship appears to be making her way past a large floe of level first-year ice that is well into the melting process. The deformed ice in the background indicates clearly that the floes are over 30 cm thick.

Figure 17 – Rafted Ice
It is obvious that the floe in the foreground is partially overriding the one behind it and vice versa. The ice thickness appears to be about 20 cm making it grey-white ice and the thin snow cover would support this estimate.

Figure 18 – Ridges and Hummocks
Moderately deformed ice carrying a rather heavy snow cover. The linear nature of the pressure ridges (R) as opposed to the isolated but higher hummocks (H) are the distinctions between these two topographic features.

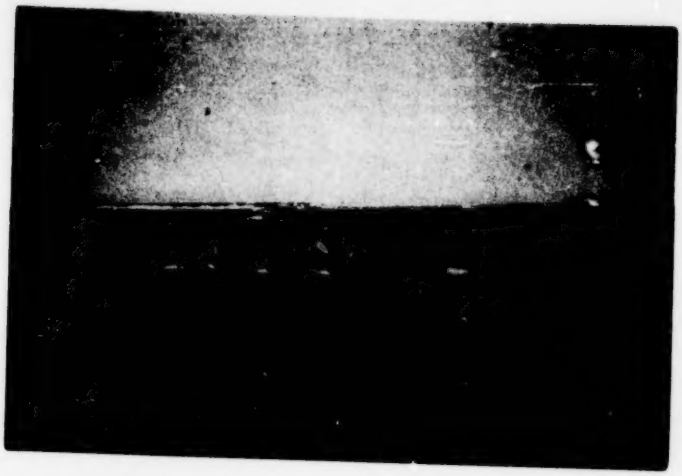


Figure 19 – Open Water
A few floes are evident but ships would have no trouble penetrating such an area. In the background there appears to be a little more ice but this may only be a result of the distant perspective.

Figure 20 – Very Open Pack Ice
The ice in this area is somewhat more evident but the ship's progress is unimpeded.

Figure 21 – Open Pack Ice
White ice covering about half of the sea surface. The floes are occasionally in contact but there is plentiful open water and they can be pushed aside fairly easily.

Figure 22 – Close Pack Ice
7 - 8 tenths white ice with a light snow cover. The floes are generally touching each other but there is still plenty of water in evidence.

Figure 23 – Very Close Pack Ice
The sea is almost completely covered with floes or ice cakes but some water is evident just ahead of the ship's bow. Concentration is nine plus.

Figure 24 – Compact or Consolidated Pack Ice
The sea is completely covered with ice but it is not evident whether the individual floes are frozen together – consolidated ice, or are just pressed together by wind and/or current as in compact ice.

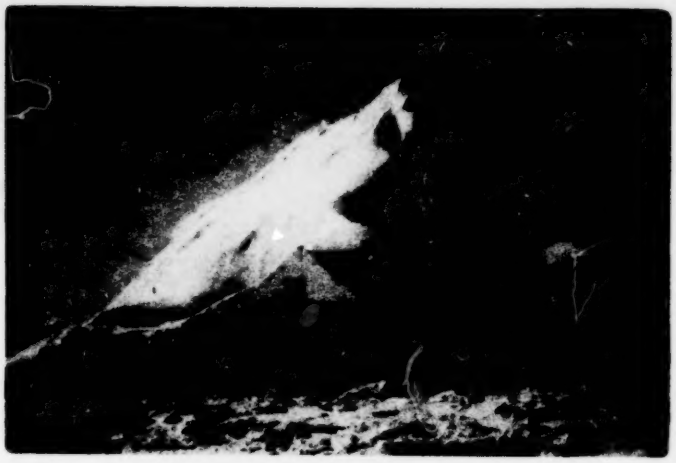


Figure 25 – Iceberg
A moderate-sized pinnacle berg surrounded by white ice which is well deformed by pressure; some "standing floes" are evident.

Figure 26 – Bergy Bit
The smooth massive shape and a blue tint reveal this as glacial ice as opposed to the brash and ice cakes of sea ice surrounding it. Detection of such hazards by radar is very difficult.

Figure 27 – Growler
A small growler in the foreground and a good-sized bergy bit in the background. Because of the roughness of the sea ice, the former would be easy to miss either visually or on a radar screen.

Appendix B

CANADIAN ICE SYMBOLS

When the AES ice reconnaissance program began, there was no international agreement on terminology or symbology for ice charts and a simple system was adopted from the practices of the U.S. Naval Hydrographic Office. It showed the amount of ice by numerical report and by a system of hatching, it reported variations in age (thickness) by printing a percentage breakdown of several classes of ice, and also indicated three ranges of floe size.

A few years later an internationally accepted terminology became available and the ice service began its use in 1962. Difficulties in facsimile relay of the ice data and in the complexity of the notations led to the development of a unique Canadian symbology that was introduced in 1966, modified in 1967 and has remained in this form until the present. The international terminology itself has remained in use, including all modifications.

This Canadian system conveys information concerning ice amount and age (thickness) simultaneously in digital form. The basis of the system is that the **amount (in tenths) of ice in each of 6 age categories is reported in an invariable order:**

Multi-Year Ice
Second-Year Ice
First-Year Ice (White Ice)
Grey-White Ice
Grey Ice
Nilas and New Ice

The older (thicker) forms are omitted if they are not present but the amount of the thinner types (or a zero if there is none) is always required. This means that **NILAS AND NEW ICE ARE ALWAYS IN THE UNITS COLUMN OF THE DIGITAL REPORT, GREY ICE IN THE TENS COLUMN, ETC.**

For Example:

42 indicates 4 tenths grey ice and 2 tenths of nilas or new ice.

402 indicates 4 tenths grey-white ice and the same 2 tenths of nilas or new ice. There is no grey ice.

4200 indicates 4 tenths of first-year ice with 2 tenths of grey-white ice. There is no grey, nilas or new ice.

This simple system is used in southern waters during the winter, but in the Arctic, when the older forms of ice are present the number of digits can become unwieldy, particularly when only zeros to denote the absence of an ice type are used. For this reason a second mark is introduced – a decimal point – always between second-year and the first-year ice. It is considered as part of the second-year ice report.

Thus 3.4000 would indicate 3 tenths of second-year ice with 4 tenths of first-year ice; there is no grey-white, grey, nilas or new ice. With the decimal reference point there is no need to report the zeros, for their function is merely to put the 4 into the proper column. The report 3.40 conveys the same information, the single zero being added by convention as a reminder.

Examples:

21.60 is 2 tenths multi-year ice, 1 tenth second-year ice, 6 tenths first-year ice and no younger forms.

1.420 is 1 tenth second-year ice, 4 tenths first-year ice, 2 tenths grey-white ice and no younger forms.

Notice that in the freeze up period the full report is usually required : 2.0014 for example.

FLOE SIZE

In addition to the amount of ice in each class which is present, the floe size of the ice also has an effect on the progress a ship can make through the ice. For this reason the amount of medium floe or greater is also reported. This appears on the second line of the digital report. A medium floe is one over 100 metres across.

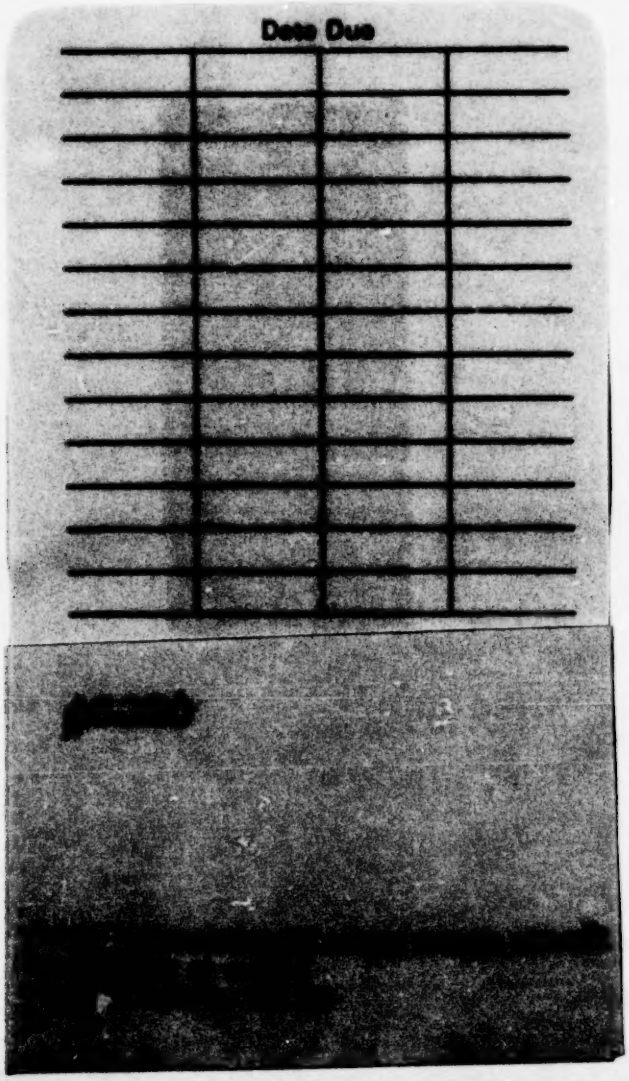
For Example:

$\frac{4210}{3\ 1}$ indicates 4 tenths of first-year ice of which 3 tenths is in floes medium size or greater; 2 tenths of grey-white ice is present, all small floe or less in size; 1 tenth of grey ice is present, all medium floe or larger.

OTHER FEATURES

(a) A solidus (/) is used to indicate some floes but less than 1 tenth of an age class.

(b) When more than nine and less than ten tenths (nine plus) of ice is present the concentration by age class will total ten and the report is circled: (8101)

(c) To distinguish between 1 tenth of an age class and ten tenths of the next lowest, a change in digit size is mandatory, this 100 is one tenth of grey-white ice; 10o is ten tenths of grey ice.

(d) An optional hatching pattern is available which is selected on the basis of the total amount of ice present and its predominant age. It is used mostly in radio facsimile broadcasts.